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Fishbine et al.
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[54] METHODS FOR DIGITALLY NOISE AVERAGING AND ILLUMINATION EQUALIZING FINGERPRINT IMAGES

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[73] Assignee: C.F.A. Technologies, Inc., St. Louis, Minn.

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[22] Filed: Feb. 27, 1987
[51] Int. Cl.⁴ G06K 9/00; G06K 9/56
[52] U.S. Cl. 382/52; 382/4; 382/54; 358/163
[58] Field of Search 382/4, 5, 52, 54; 358/163, 166

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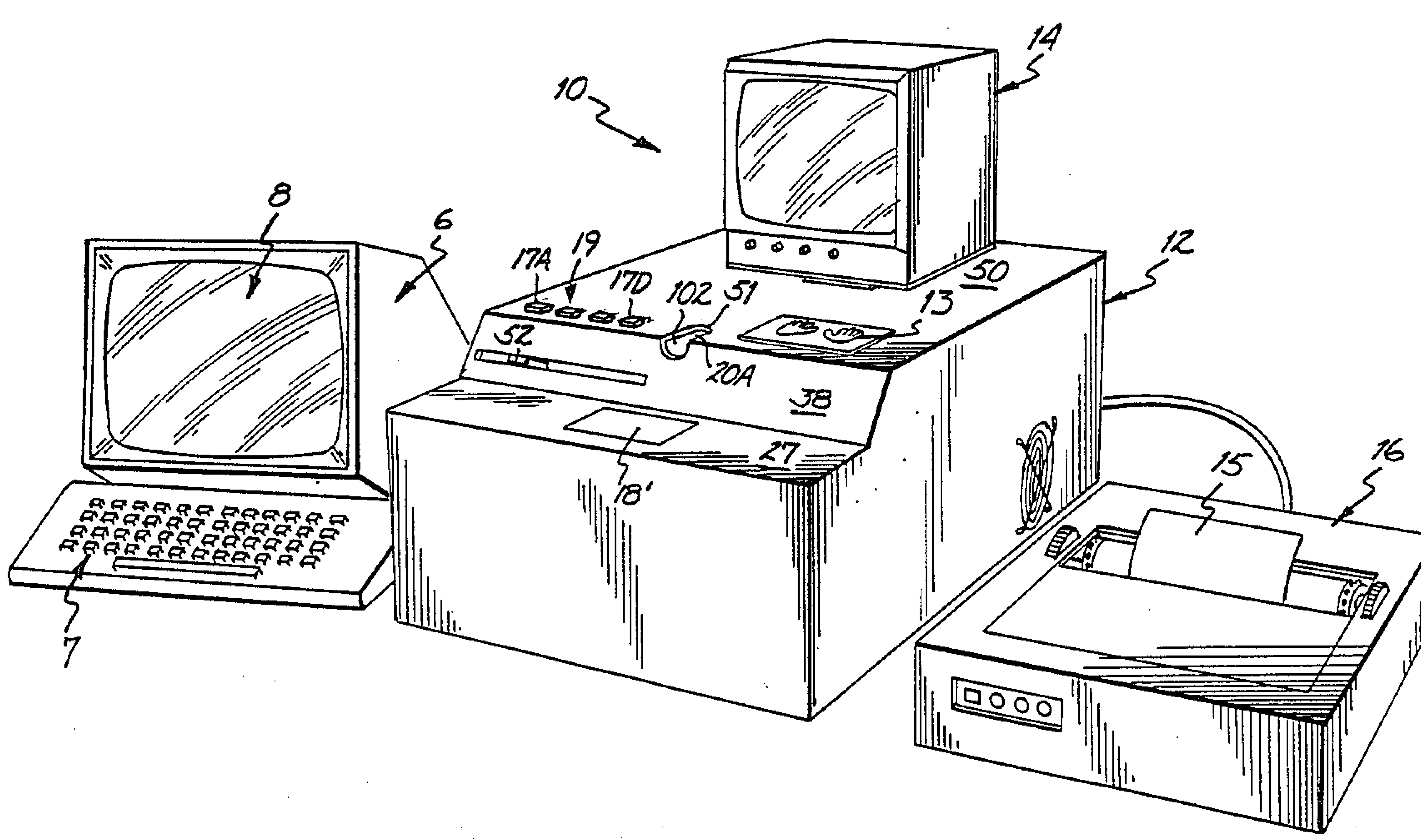
Assistant Examiner—Donald J. Daley
Attorney, Agent, or Firm—Kinney & Lange

[57] ABSTRACT

Methods for operating a programmable digital computer to enhance images of fingerprints represented by an array of pixel values. Methods for noise averaging, illumination equalizing, directional filtering, unhairing, curvature correcting, and scale correcting a fingerprint image are disclosed.

7 Claims, 28 Drawing Sheets



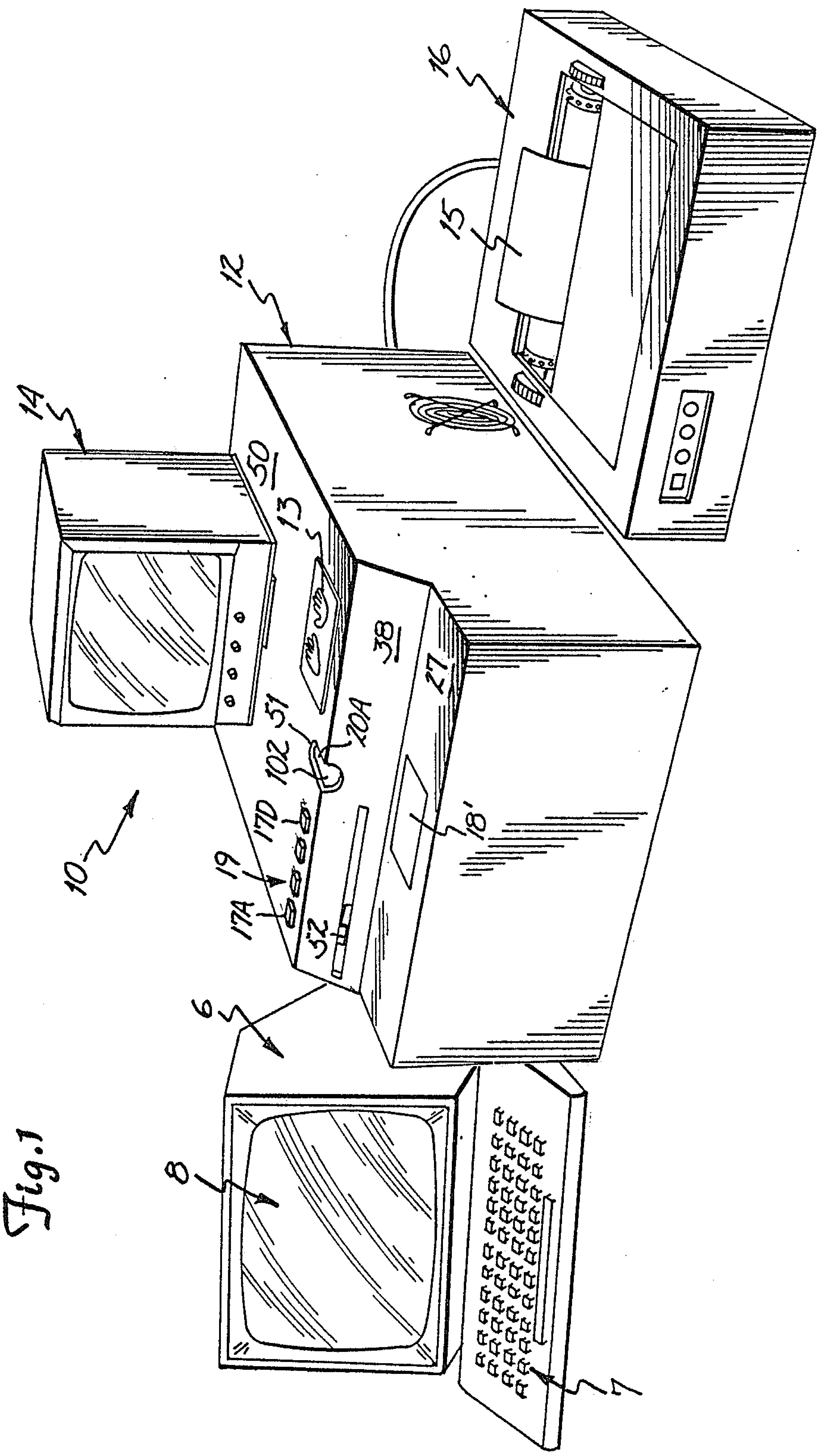
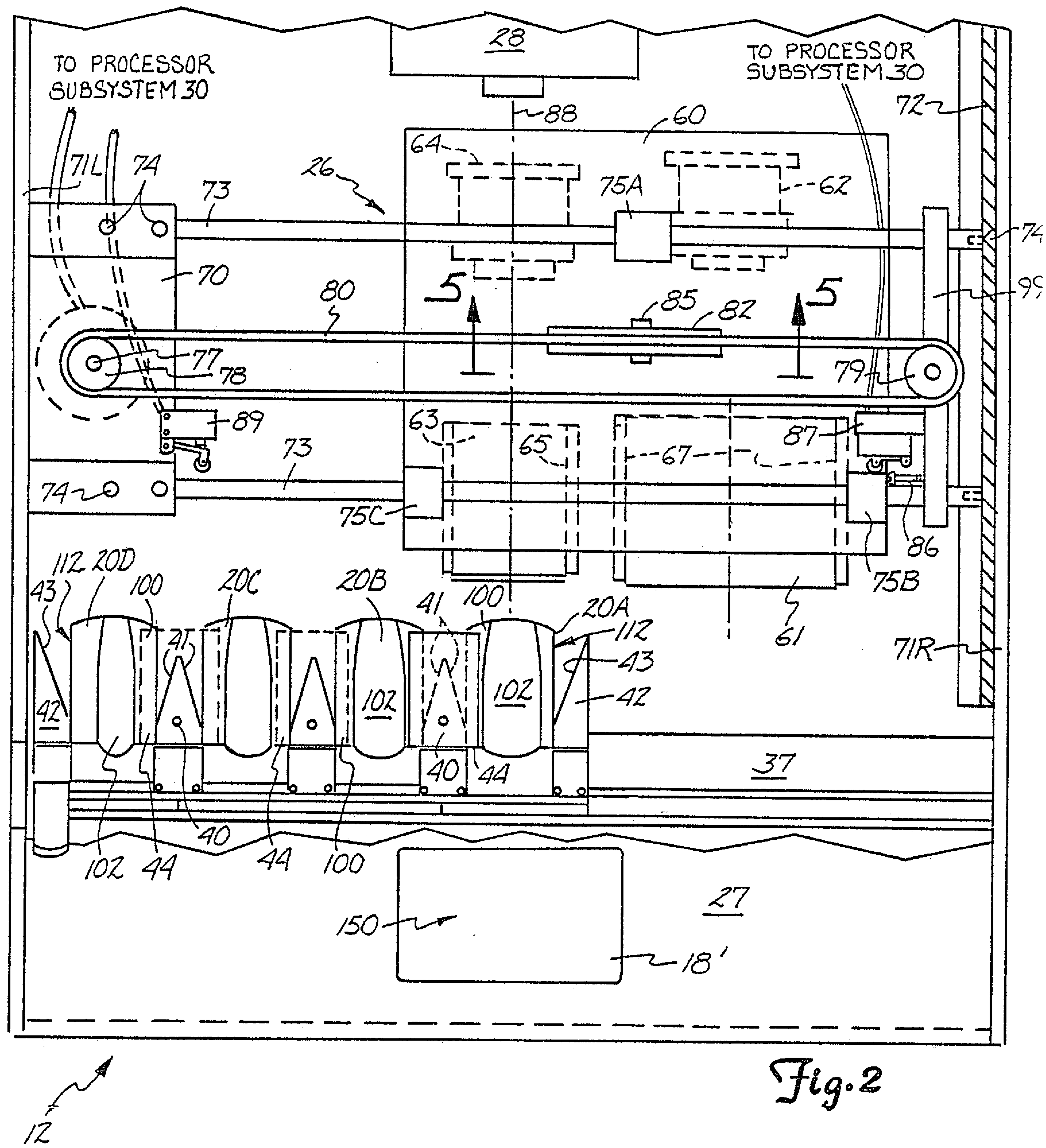


Fig.1


28
TO PROCESSOR SUBSYSTEM 30
TO PROCESSOR SUBSYSTEM 30
88
60
72
71L
74
73
26
64
75A
62
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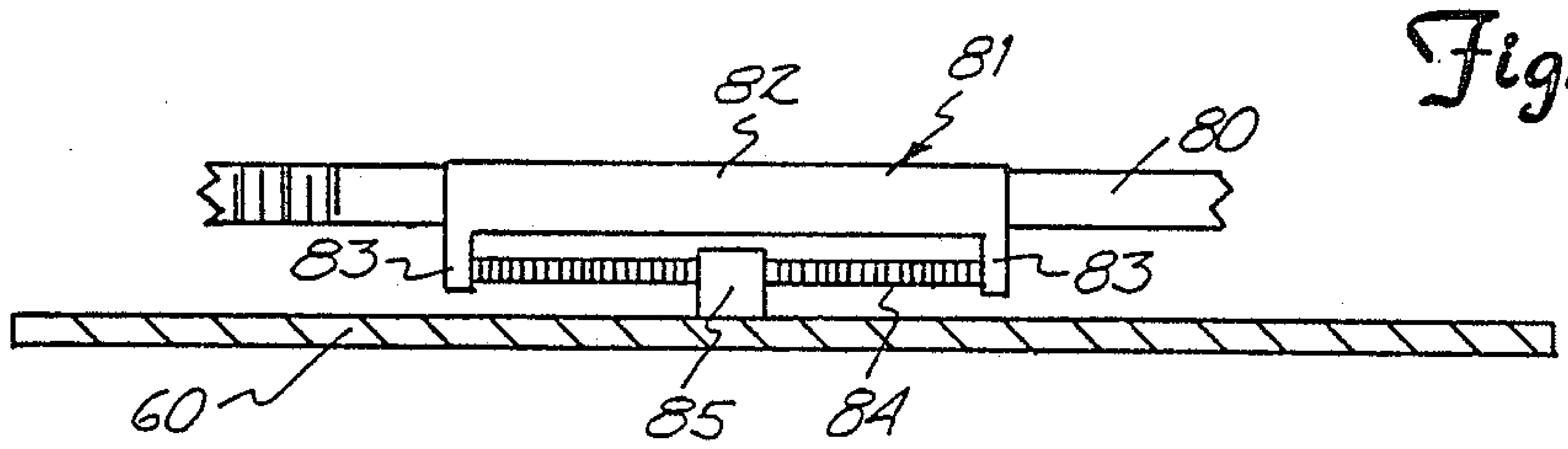
70
80
5
85
82
5
99
77
78
79
89
63
65
67
87
73
74
75C
86
75B
112
20D
100
20C
20B
41
100
20A
112
61
71R
43
41
102
102
43
42
42
40
40
44
37
102
44
40
44
100
150
27
18'
12

Fig. 2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83
83
60
85
84

Fig. 5

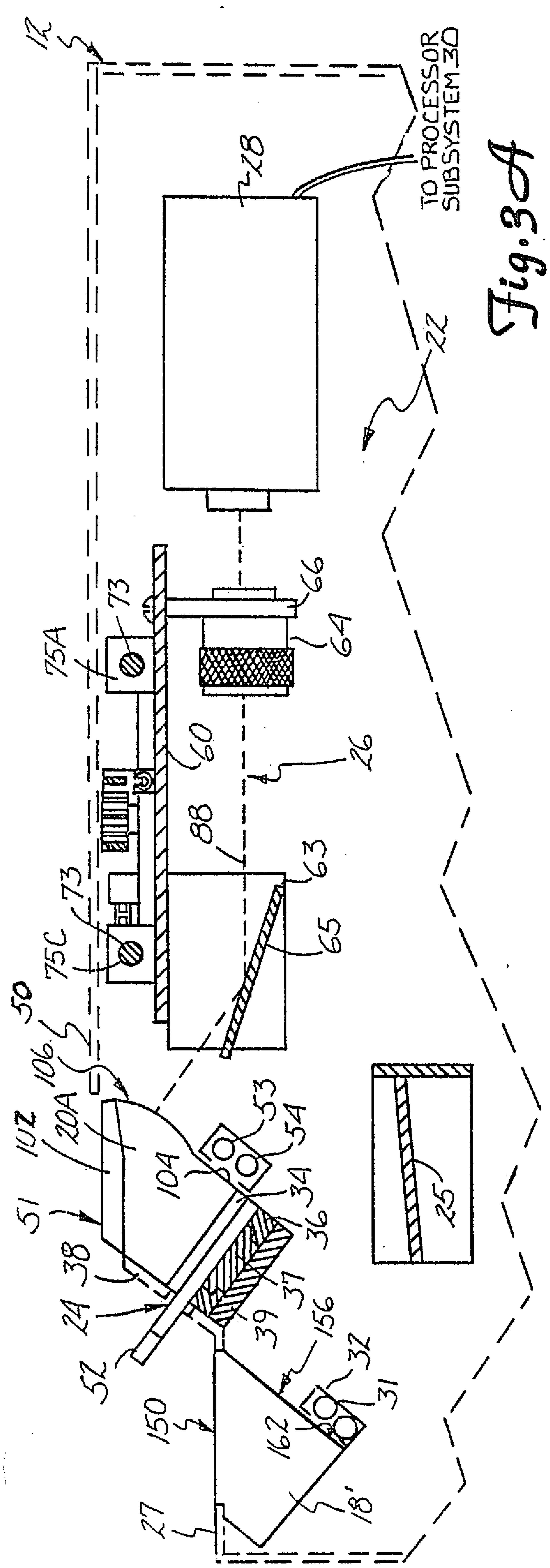


Fig.3A

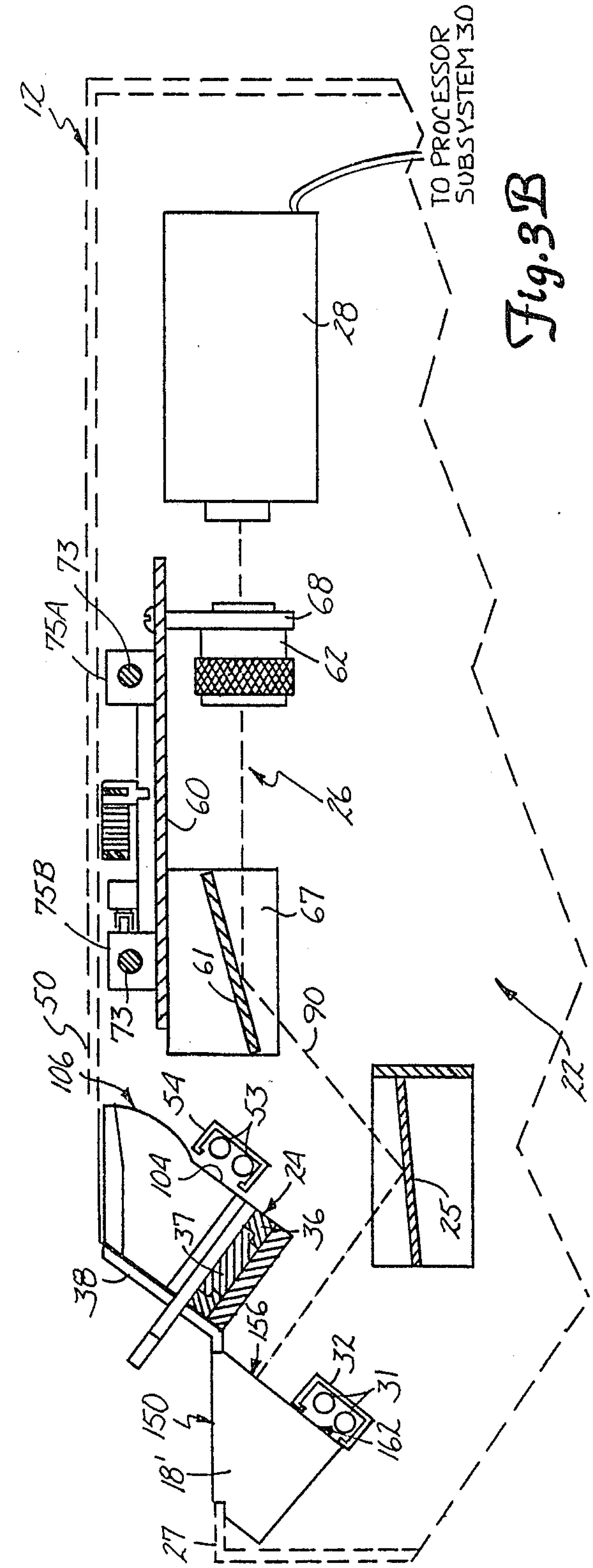
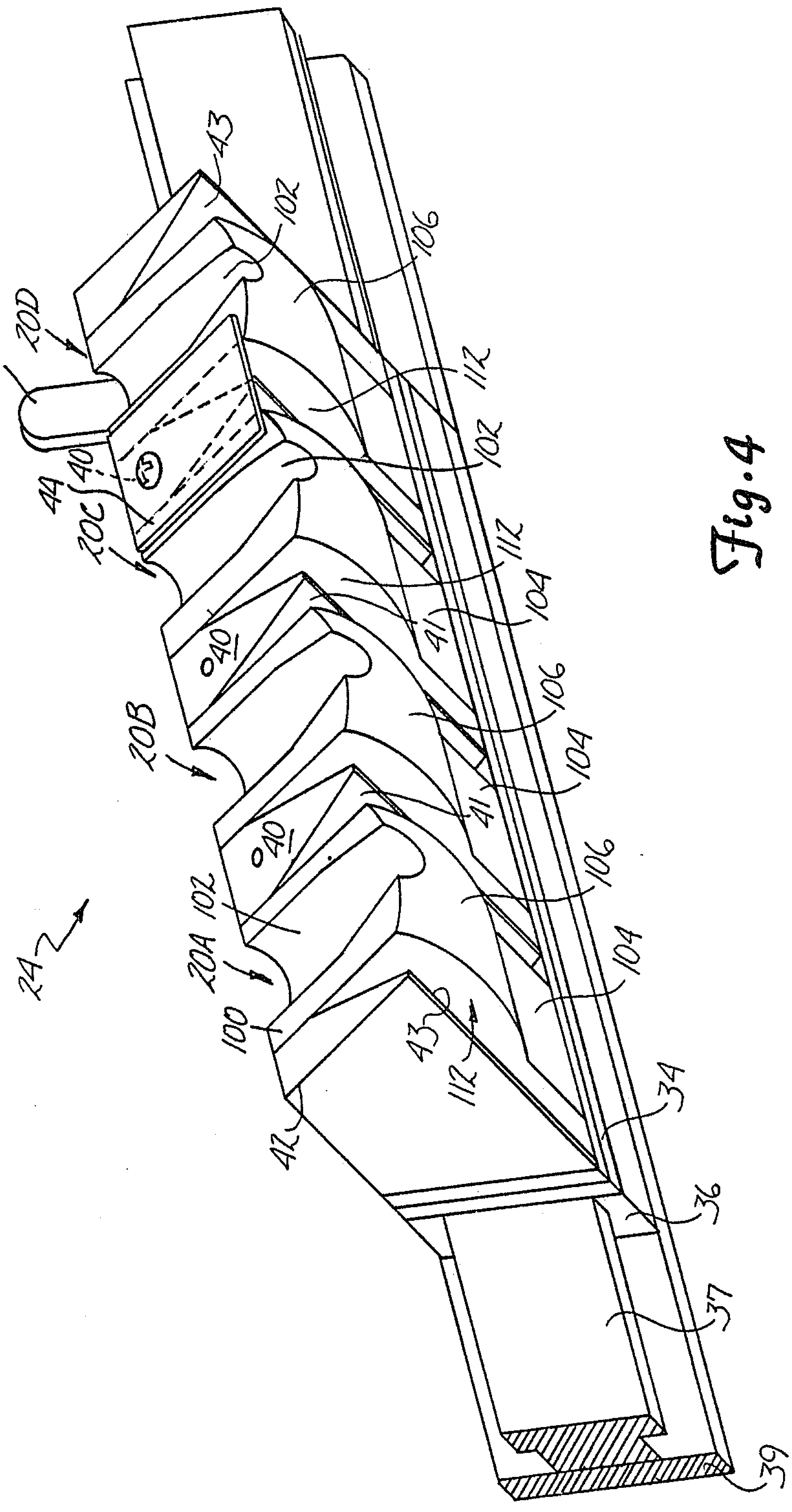


Fig.3B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102
106
20D
52
112
102
40
44
20C
112
104
40
41
106
20B
104
41
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106
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112
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34
36
37
39

Fig. 4

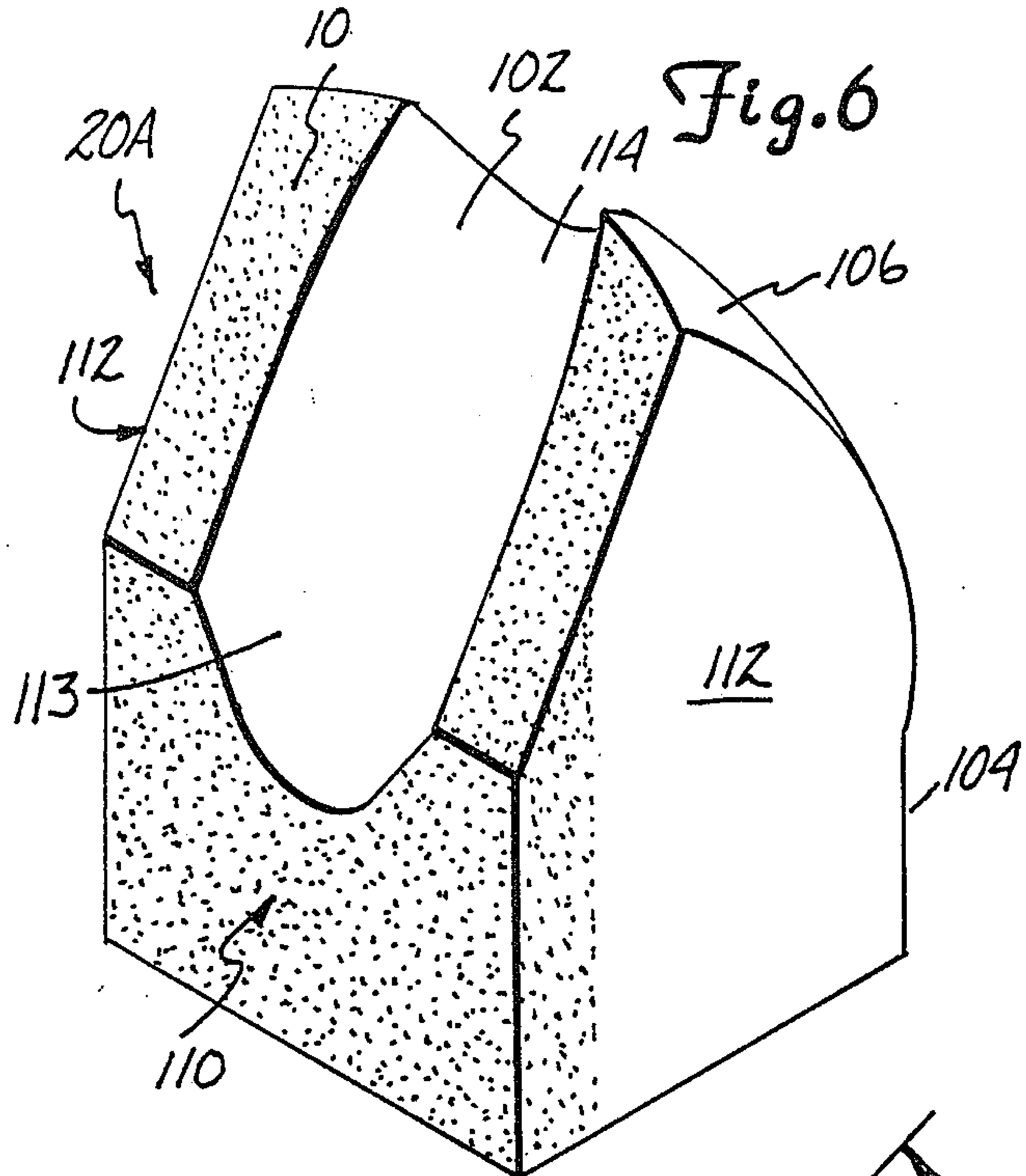


Fig.6

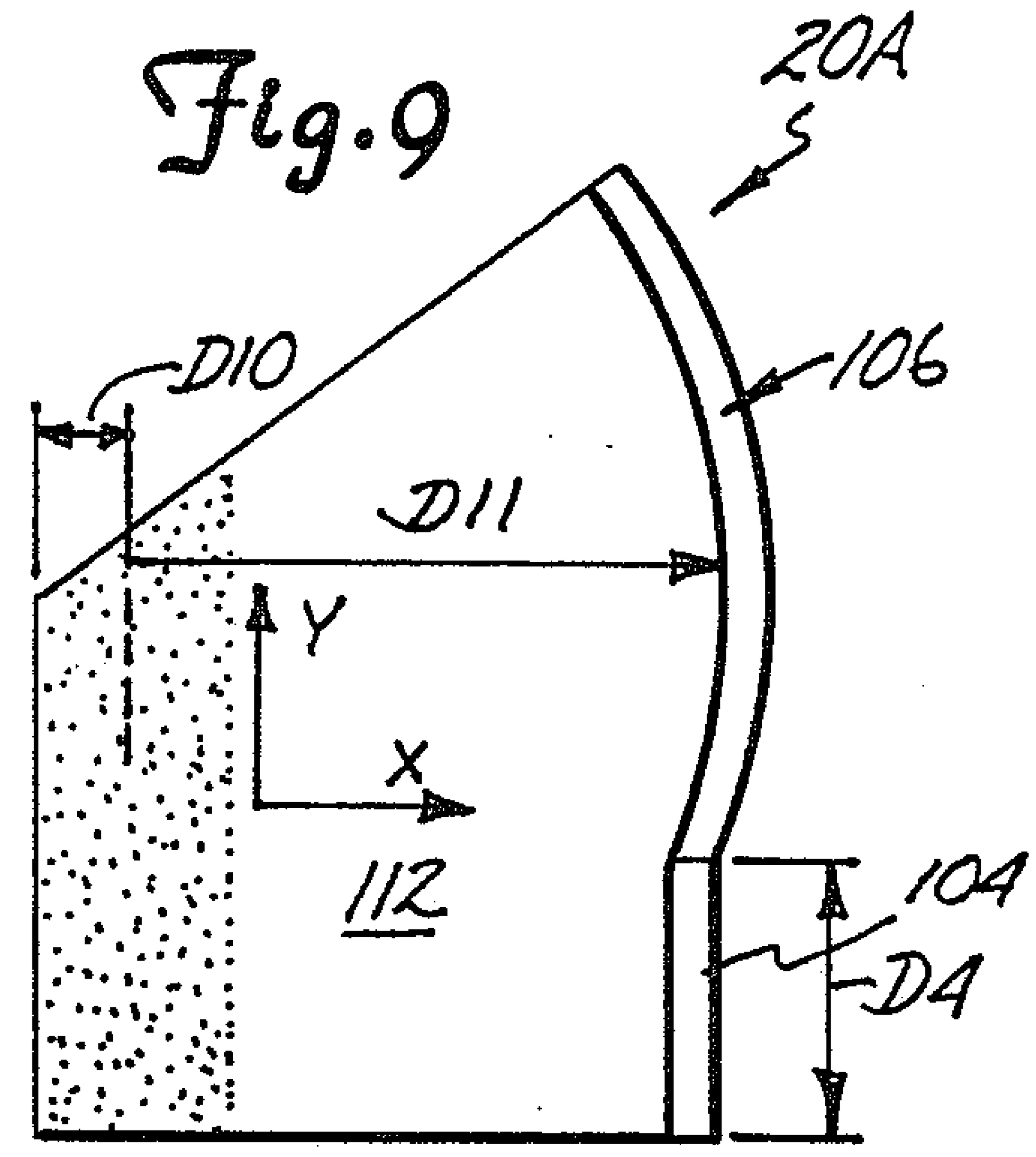


Fig.9

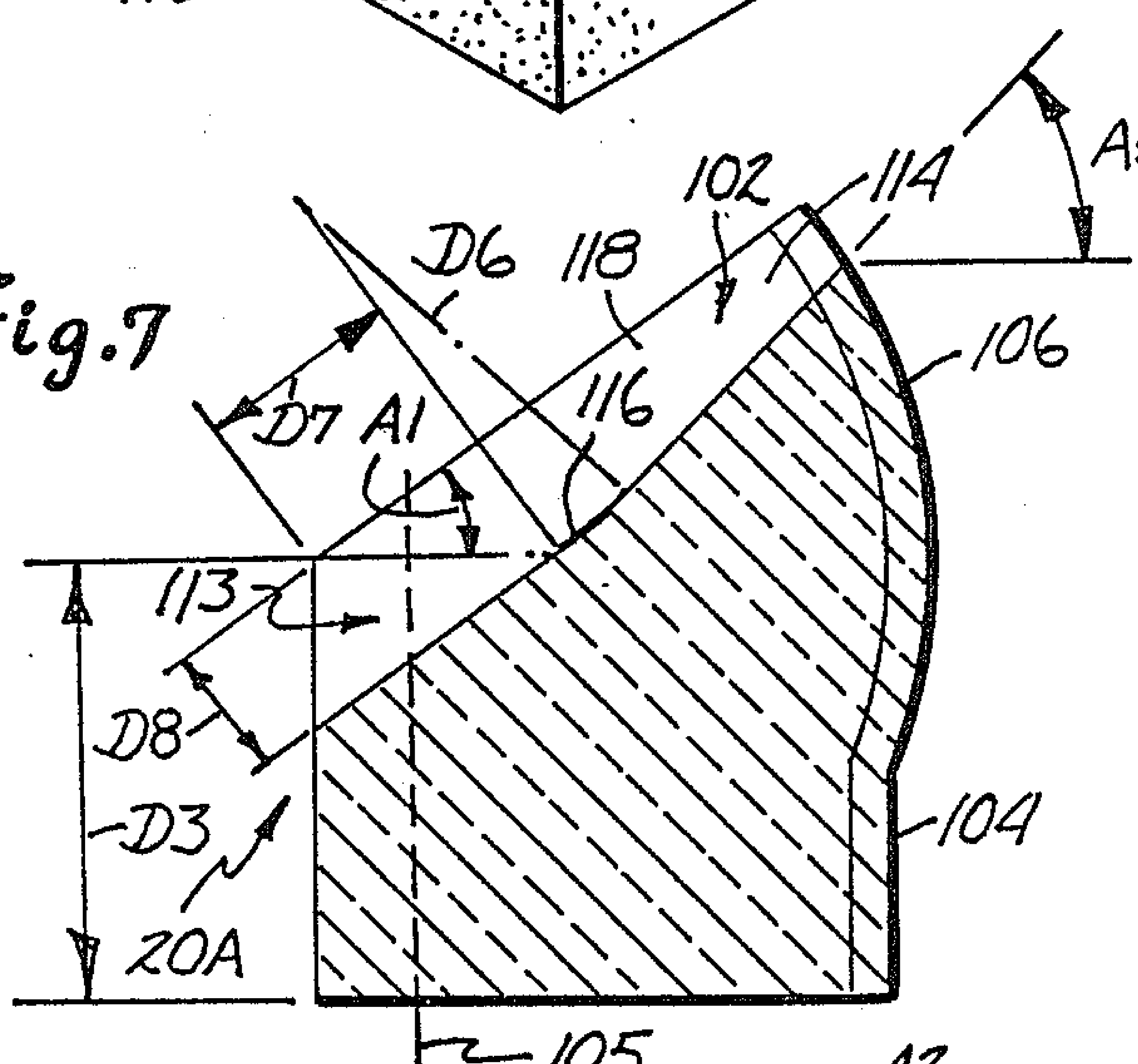


Fig.7

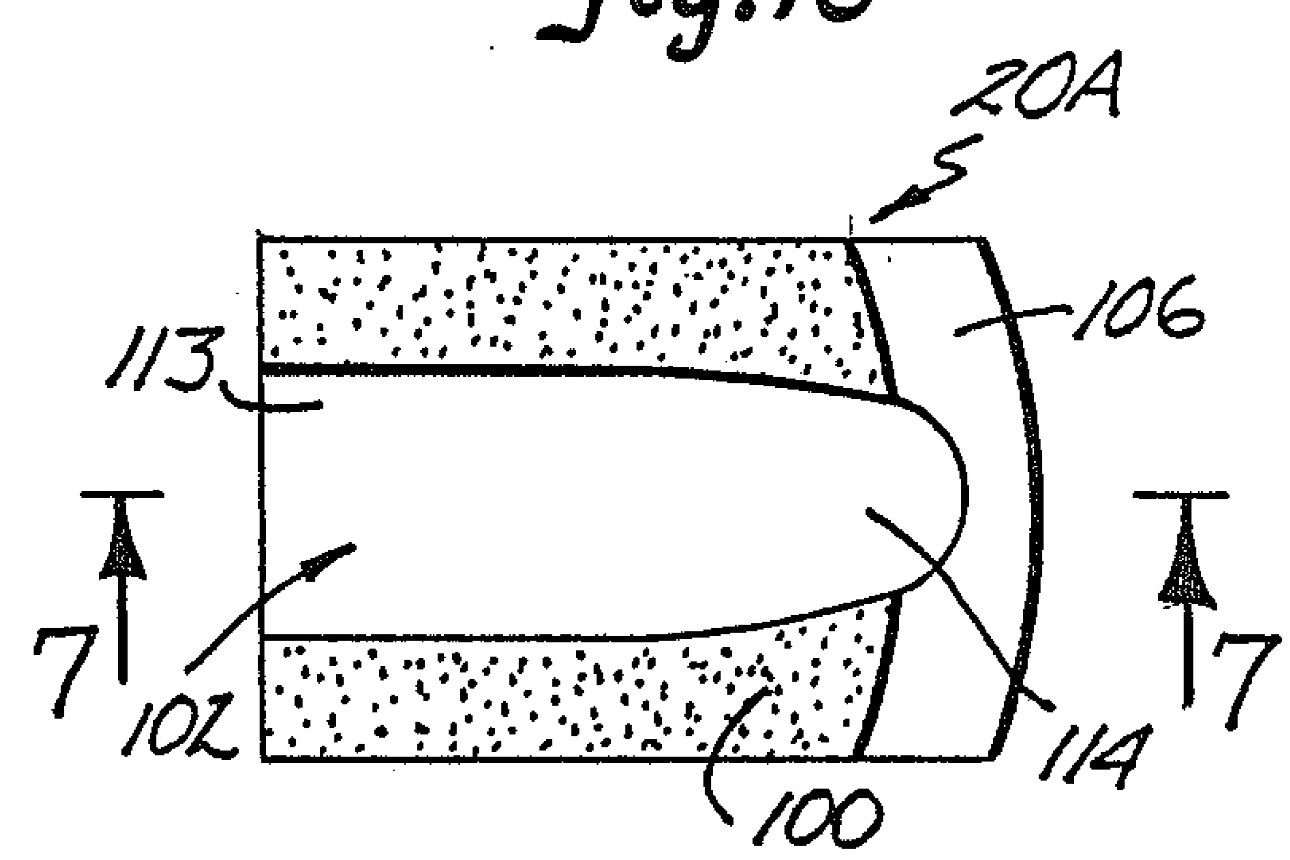


Fig.10

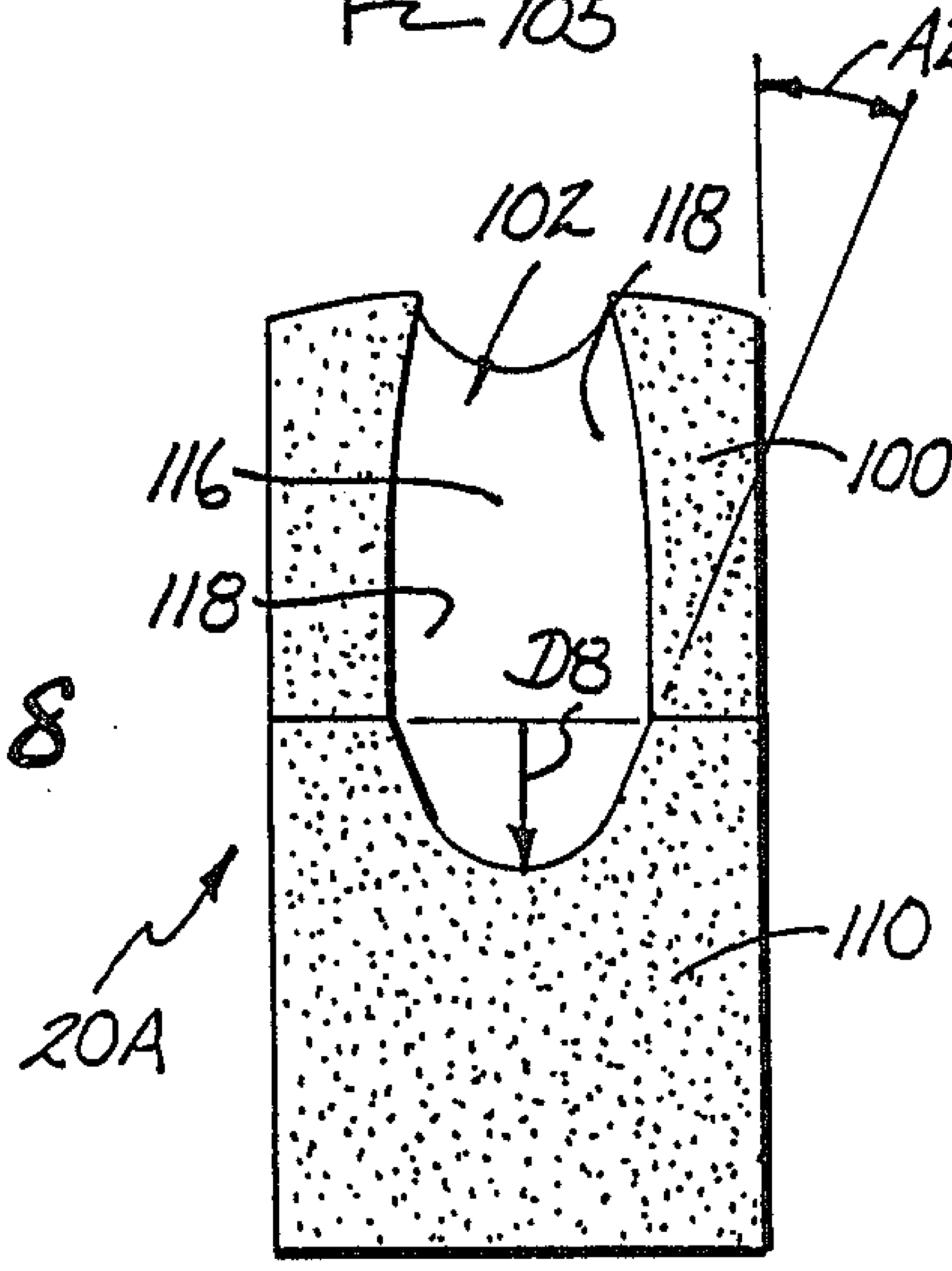


Fig.8

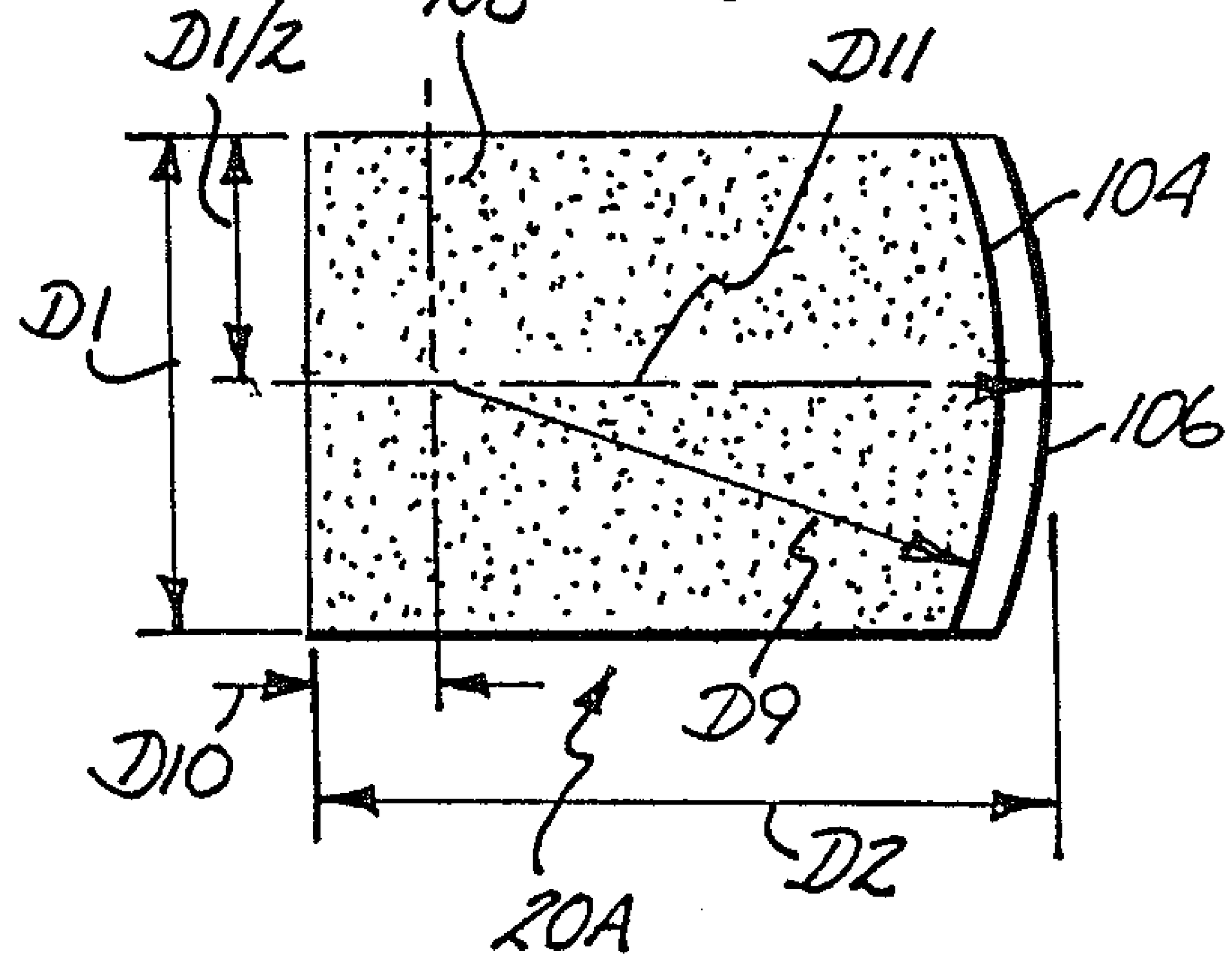


Fig 11

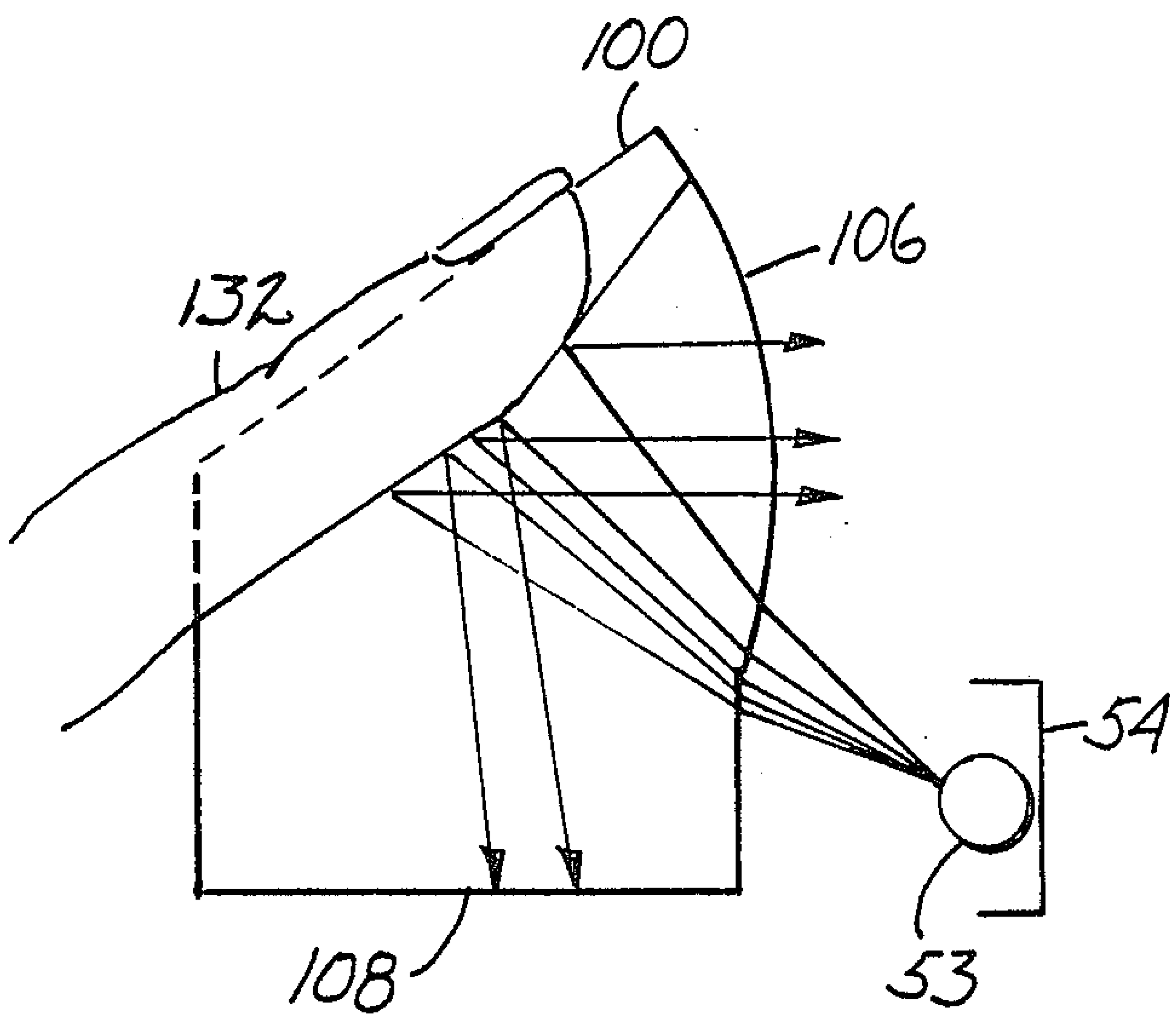


Fig.13

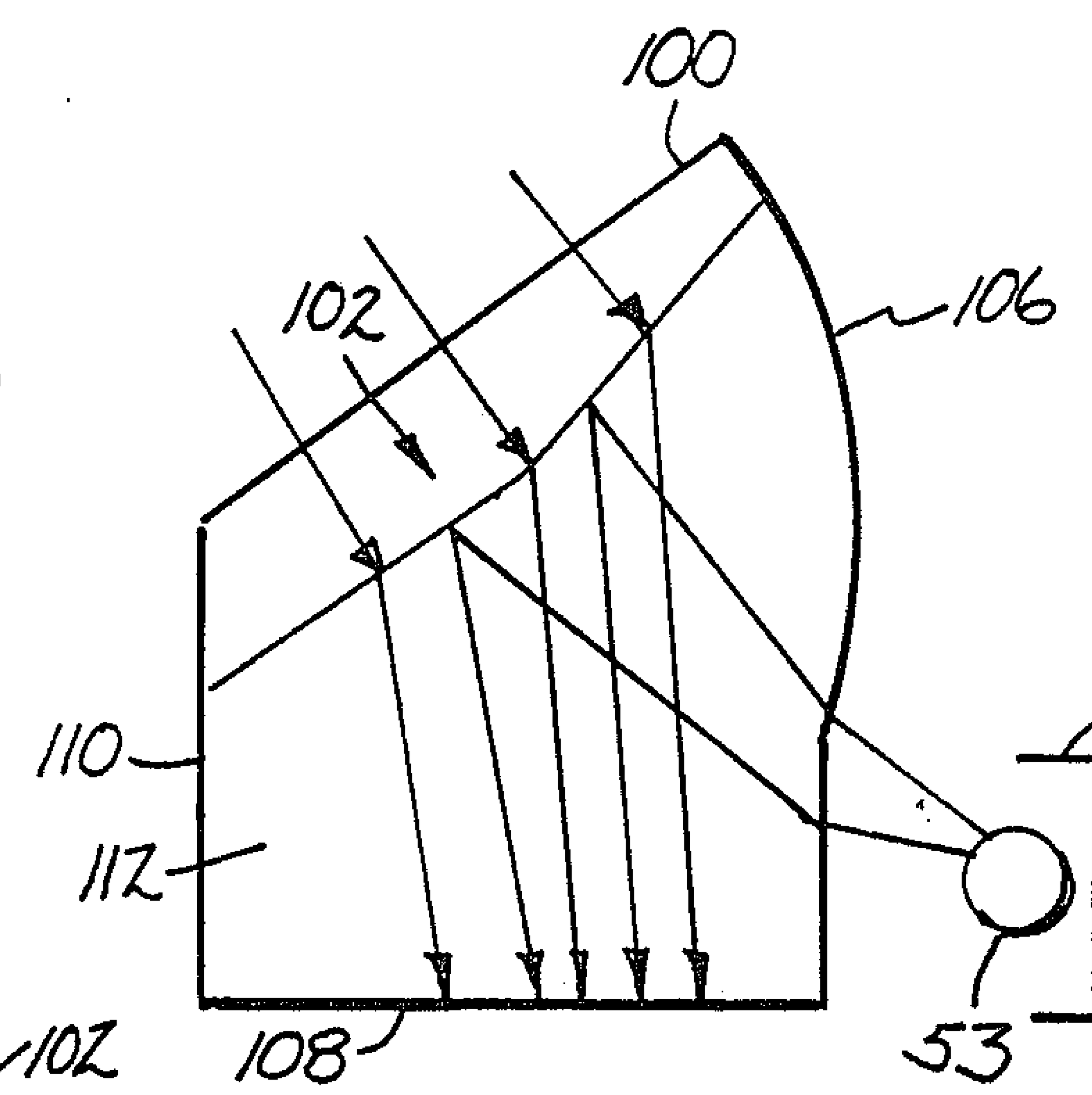


Fig.12

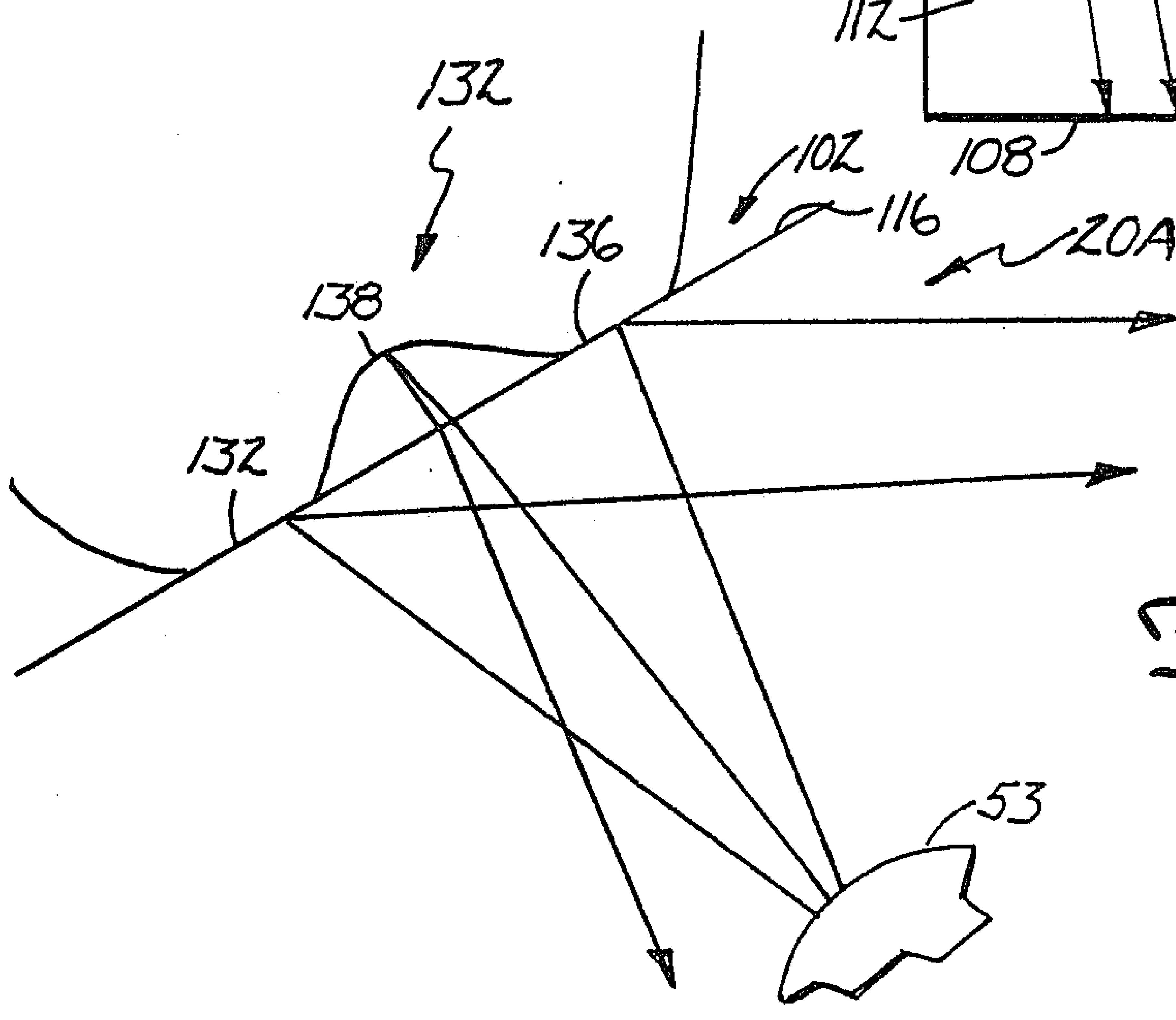


Fig.14

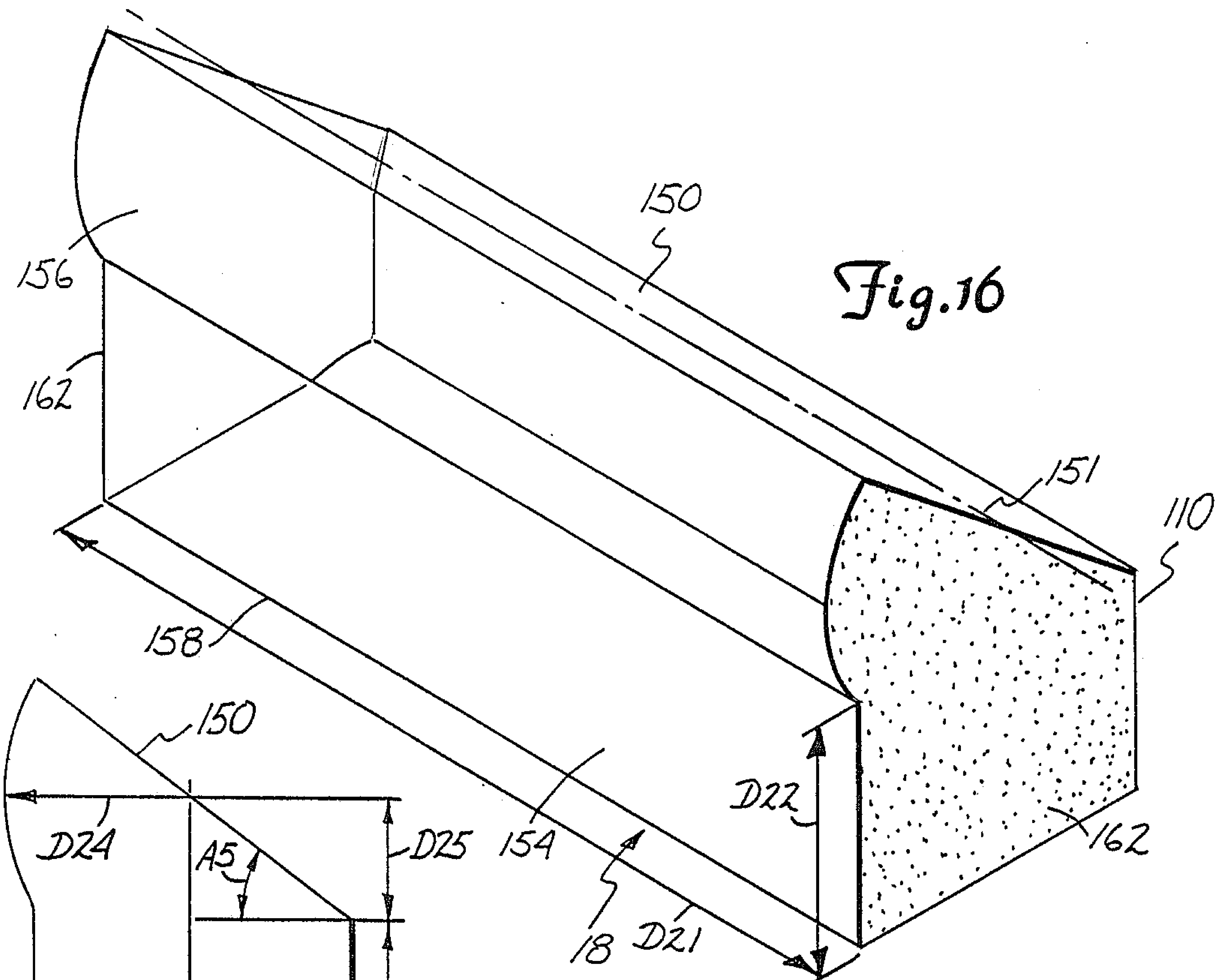


Fig.16

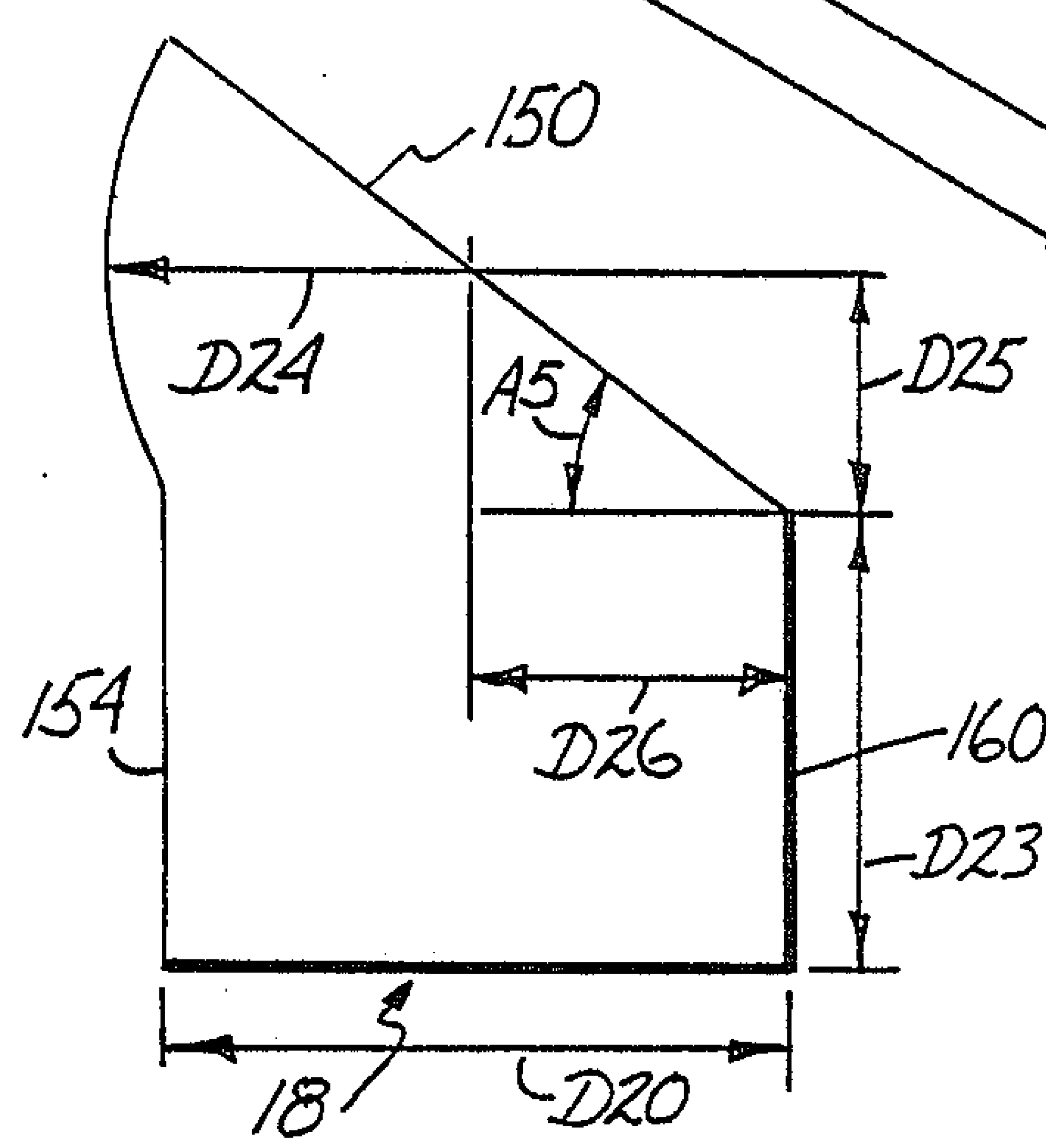


Fig.17

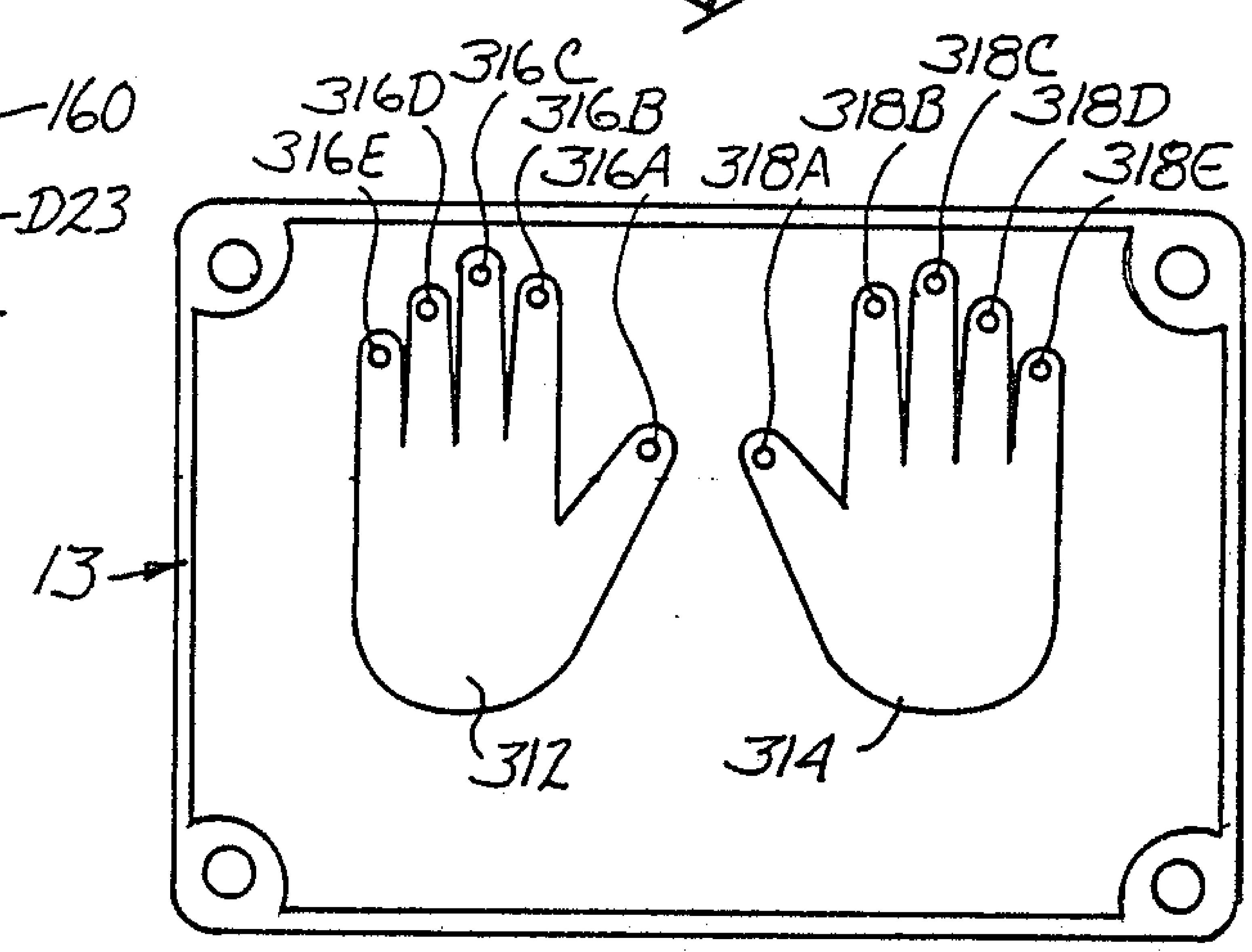


Fig.43

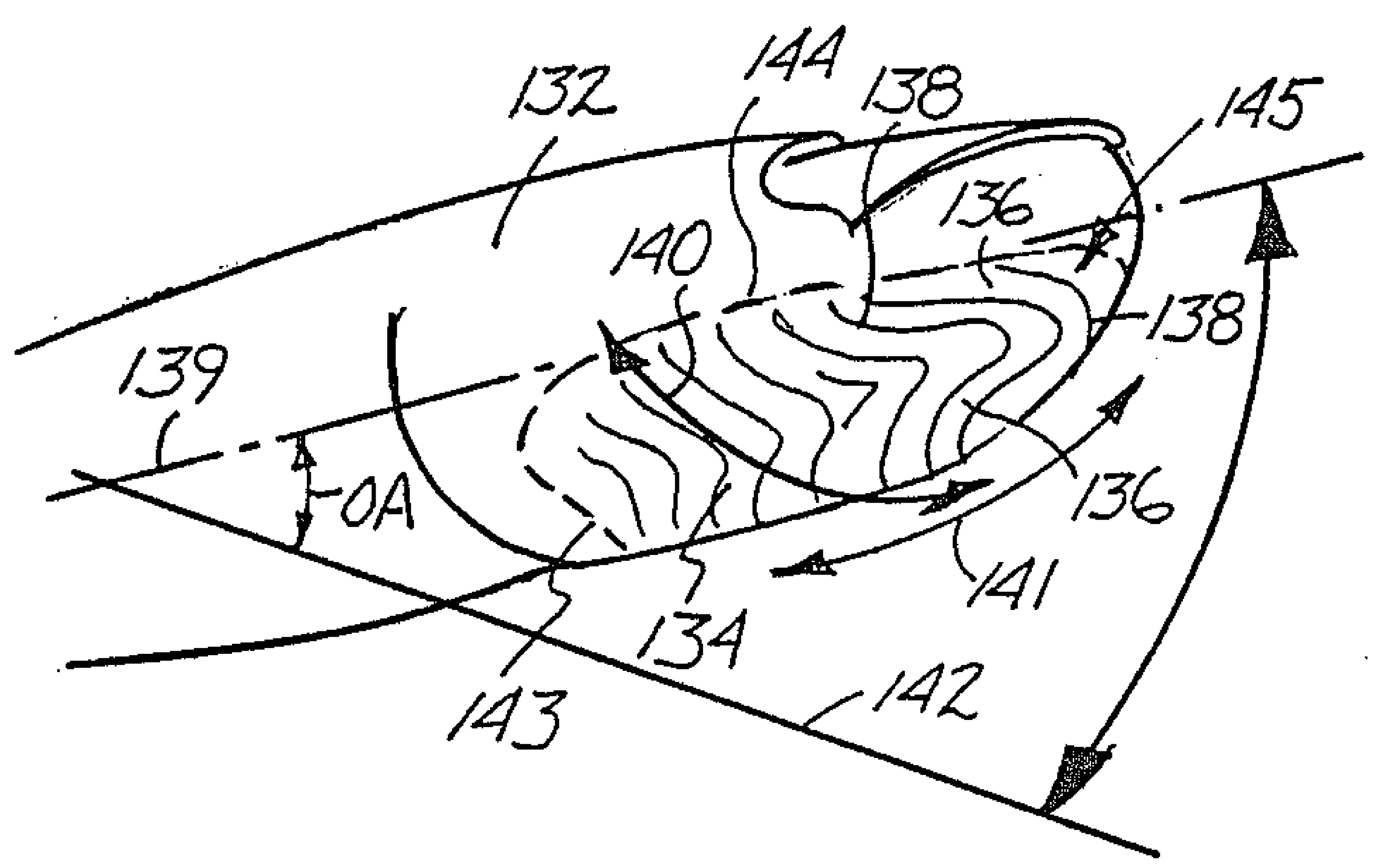


Fig.15

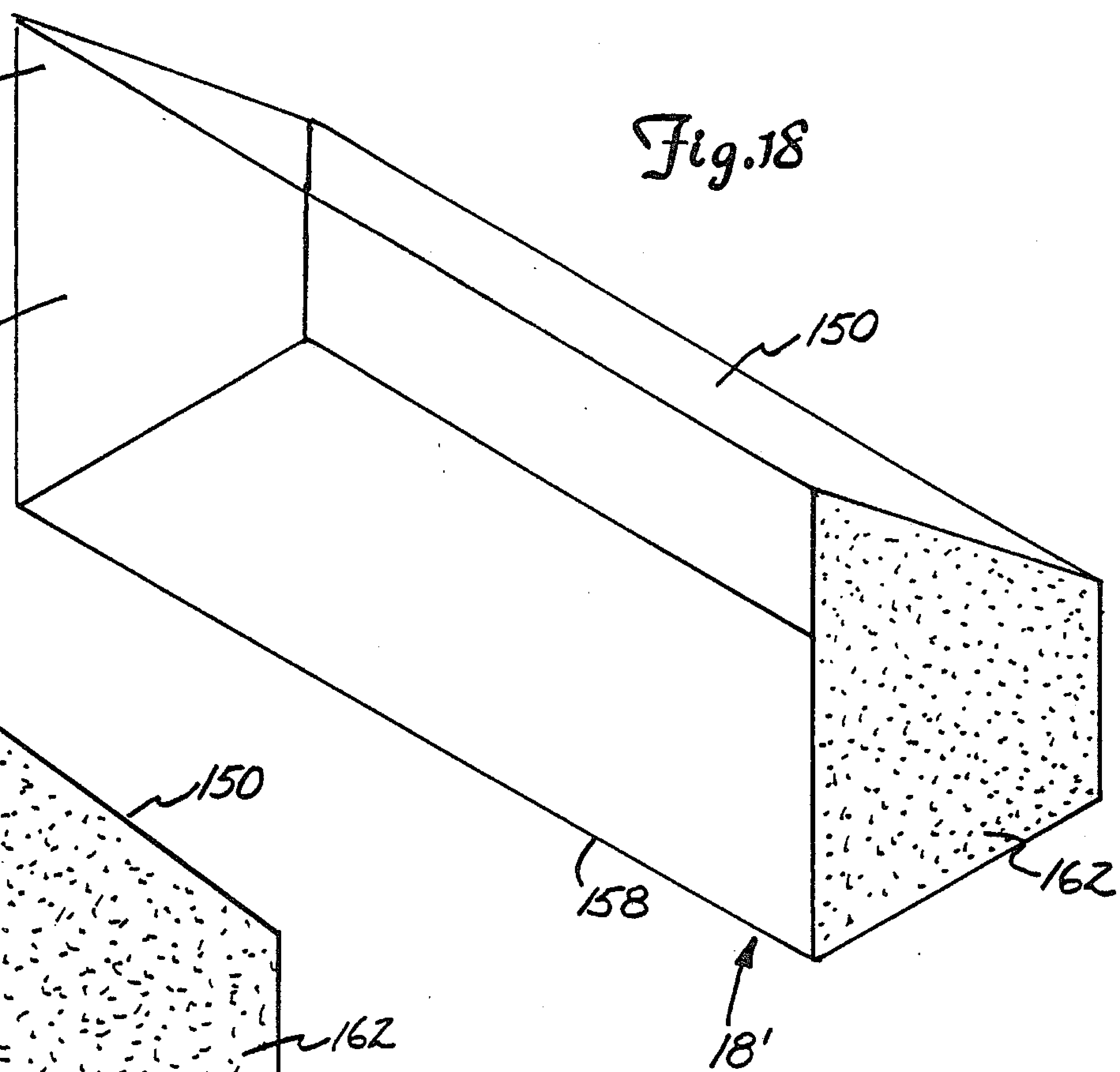


Fig.18

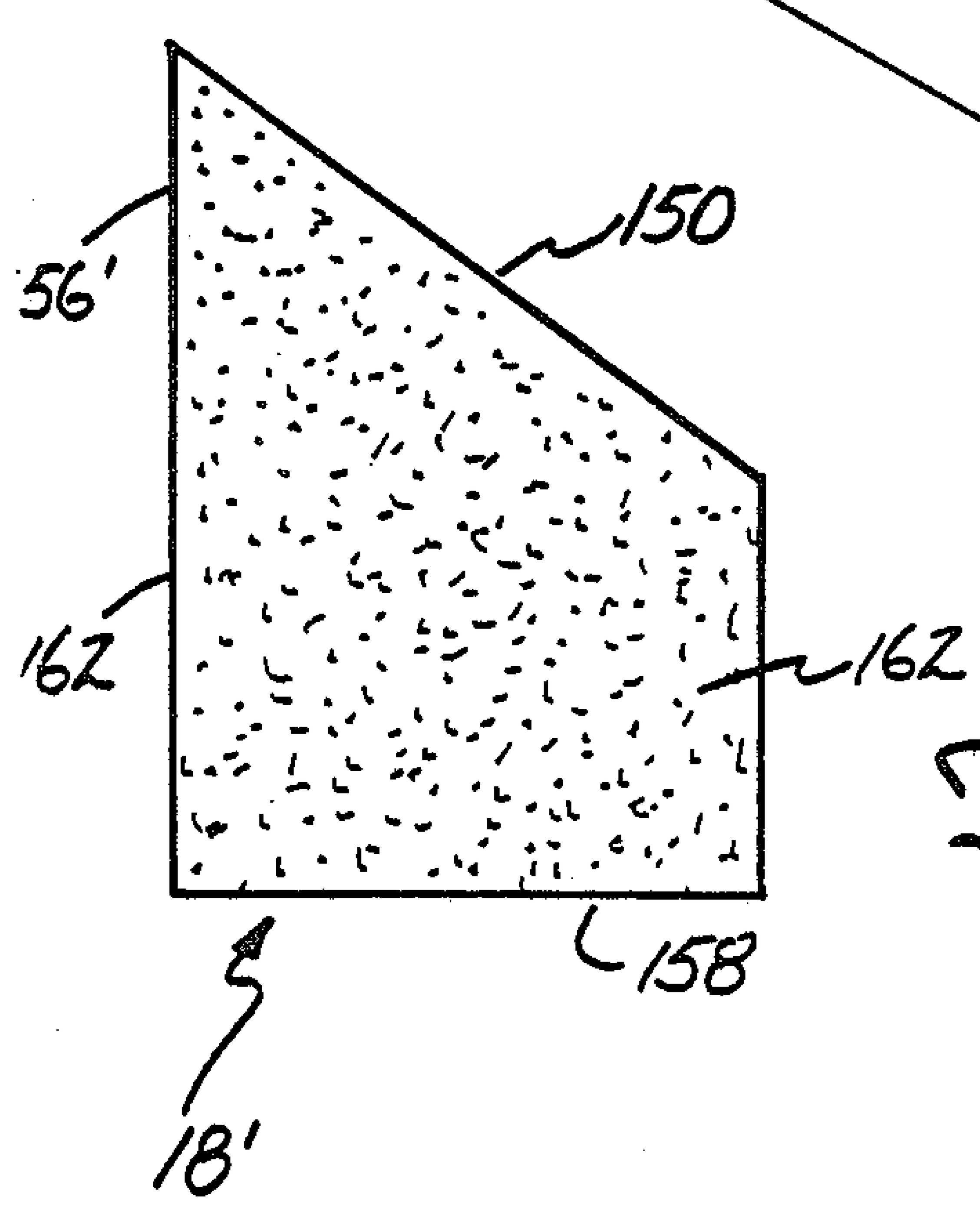
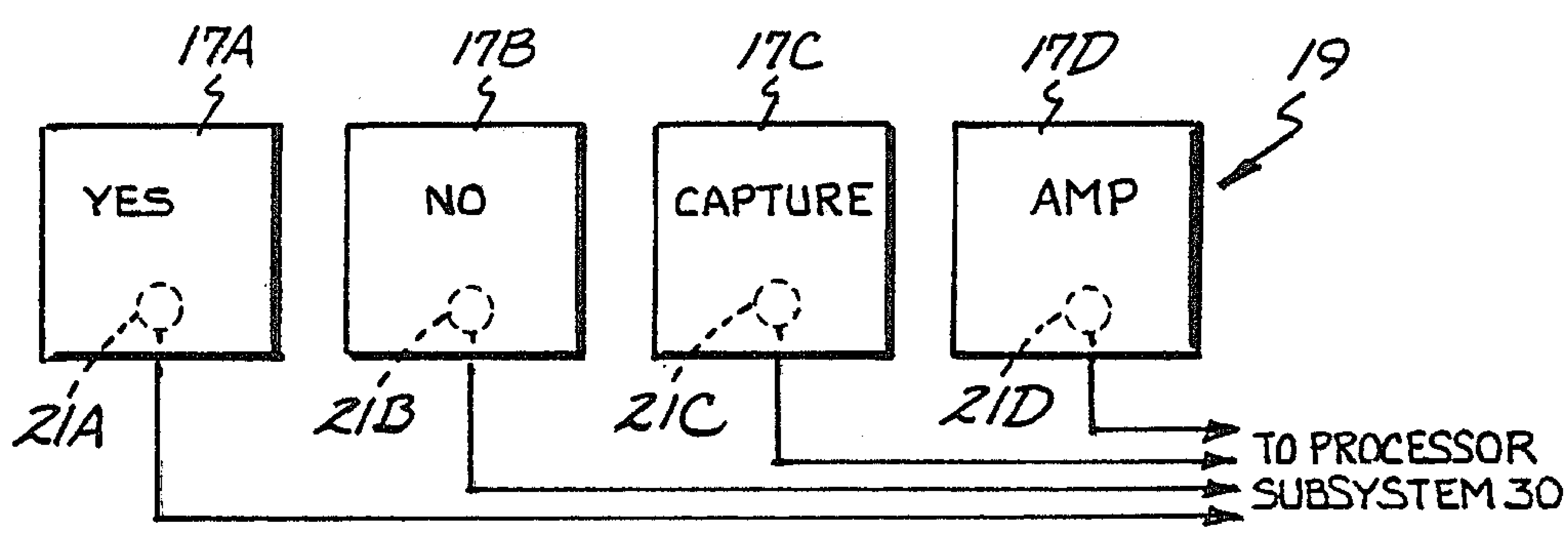
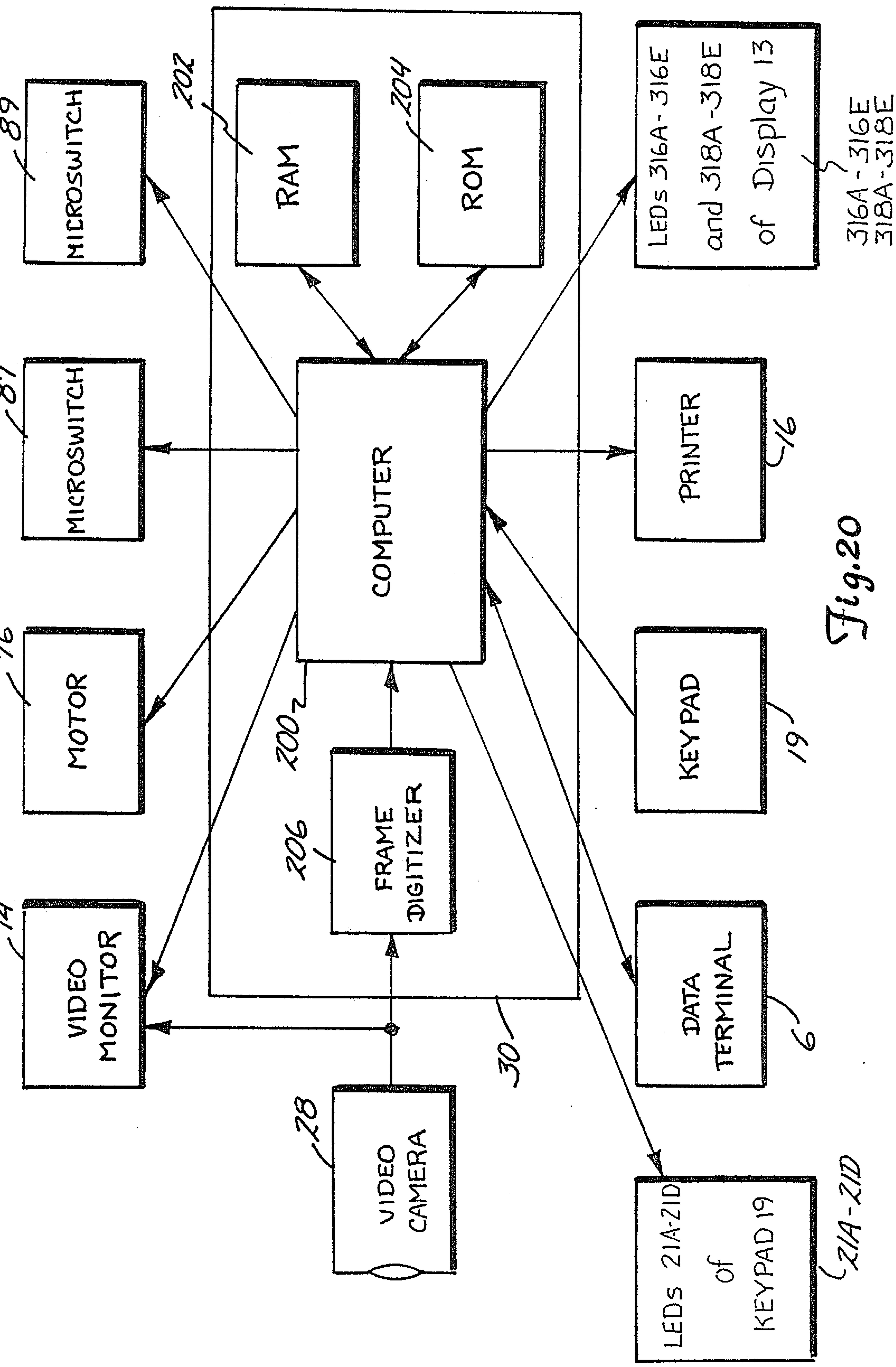


Fig.19

Fig.44

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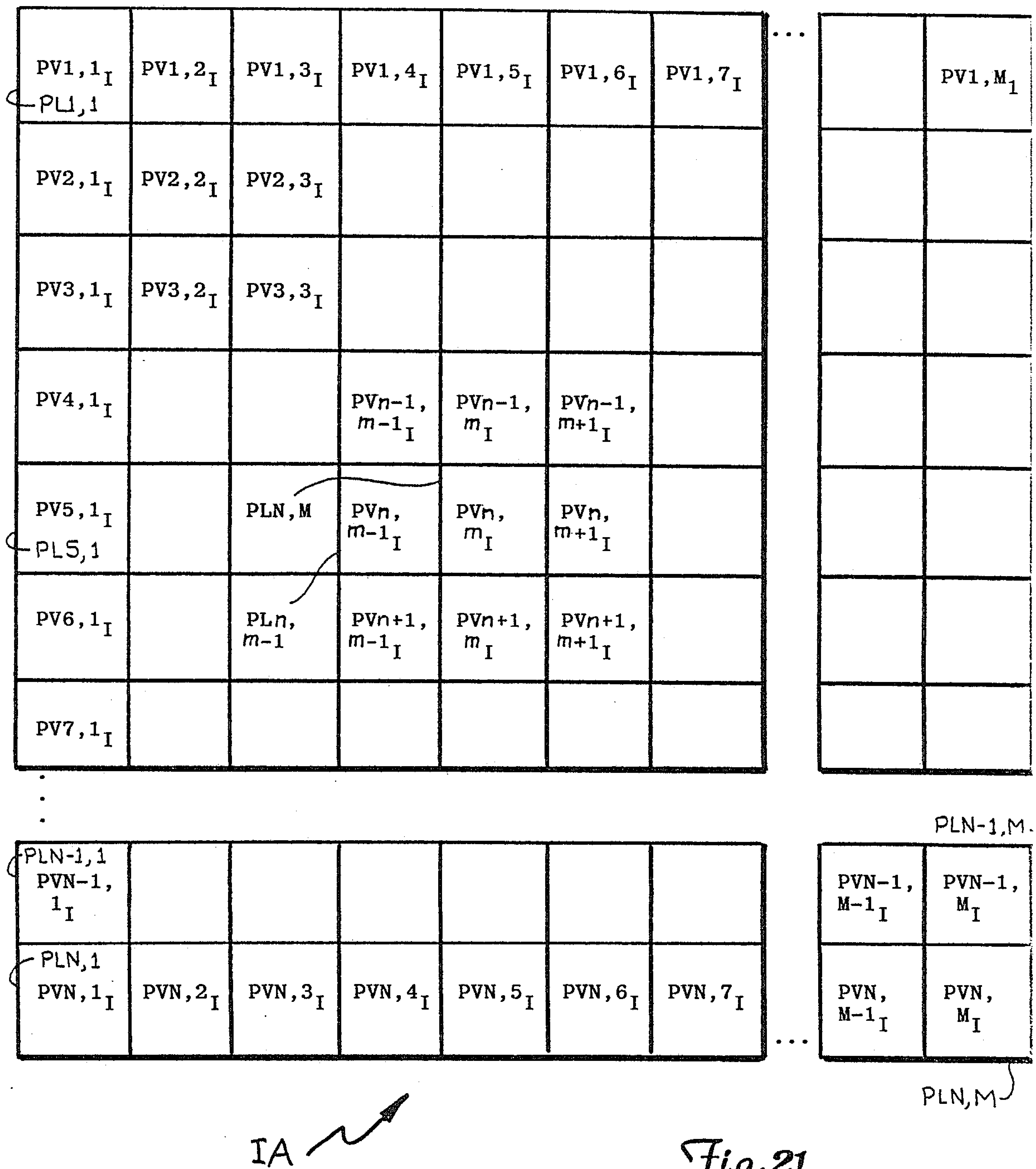
89
MICROSWITCH
87
MOTOR
76
VIDEO MONITOR
14
RAM
202
ROM
204
COMPUTER
200
FRAME DIGITIZER
206
30
VIDEO CAMERA
28
LEDs 316A-316E and 318A-318E of Display 13
316A-316E
318A-318E
PRINTER
16
KEYPAD
19
DATA TERMINAL
6
LEDs 21A-21D of KEYPAD 19
21A-21D

Fig. 20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PV1,3I
PV1,4I
PV1,5I
PV1,6I
PV1,7I
PV1,M1
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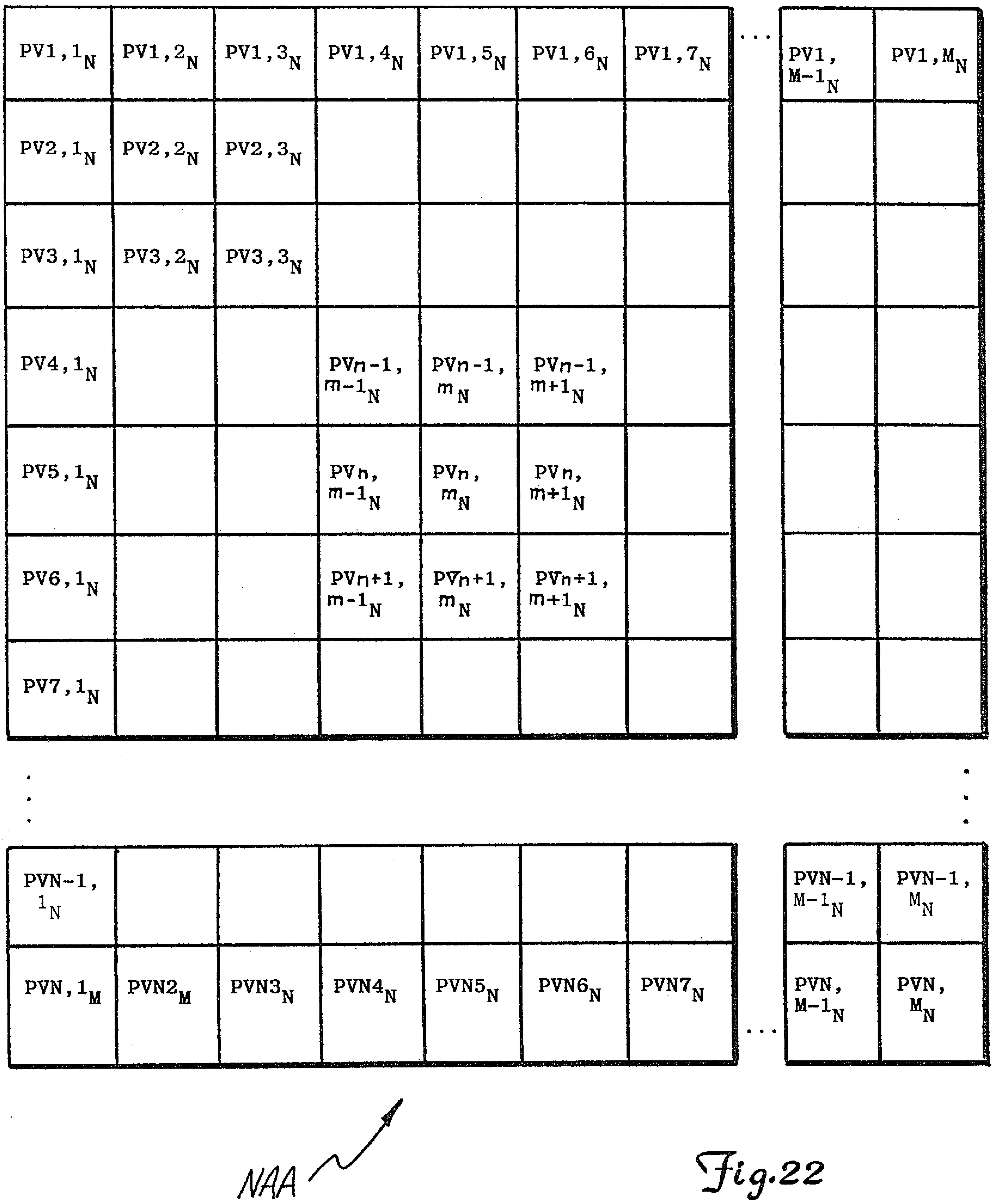
PV2,2I
PV2,3I
PV3,1I
PV3,2I
PV3,3I
PV4,1I
PVn-1, m-1I
PVn-1, mI
PVn-1, m+1I
PV5,1I
PL5,1
PLN,M
PVn, m-1I
PVn, mI
PVn, m+1I
PV6,1I
PLn, m-1
PVn+1, m-1I
PVn+1, mI
PVn+1, m+1I
PV7,1I
PLN-1,M
PLN-1,1
PVN-1, 1I
PVN-1, M-1I
PVN-1, MI
PLN,1
PVN,1I
PVN,2I
PVN,3I
PVN,4I
PVN,5I
PVN,6I
PVN,7I
PVN, M-1I
PVN, MI
PLN,M
IA

Fig.21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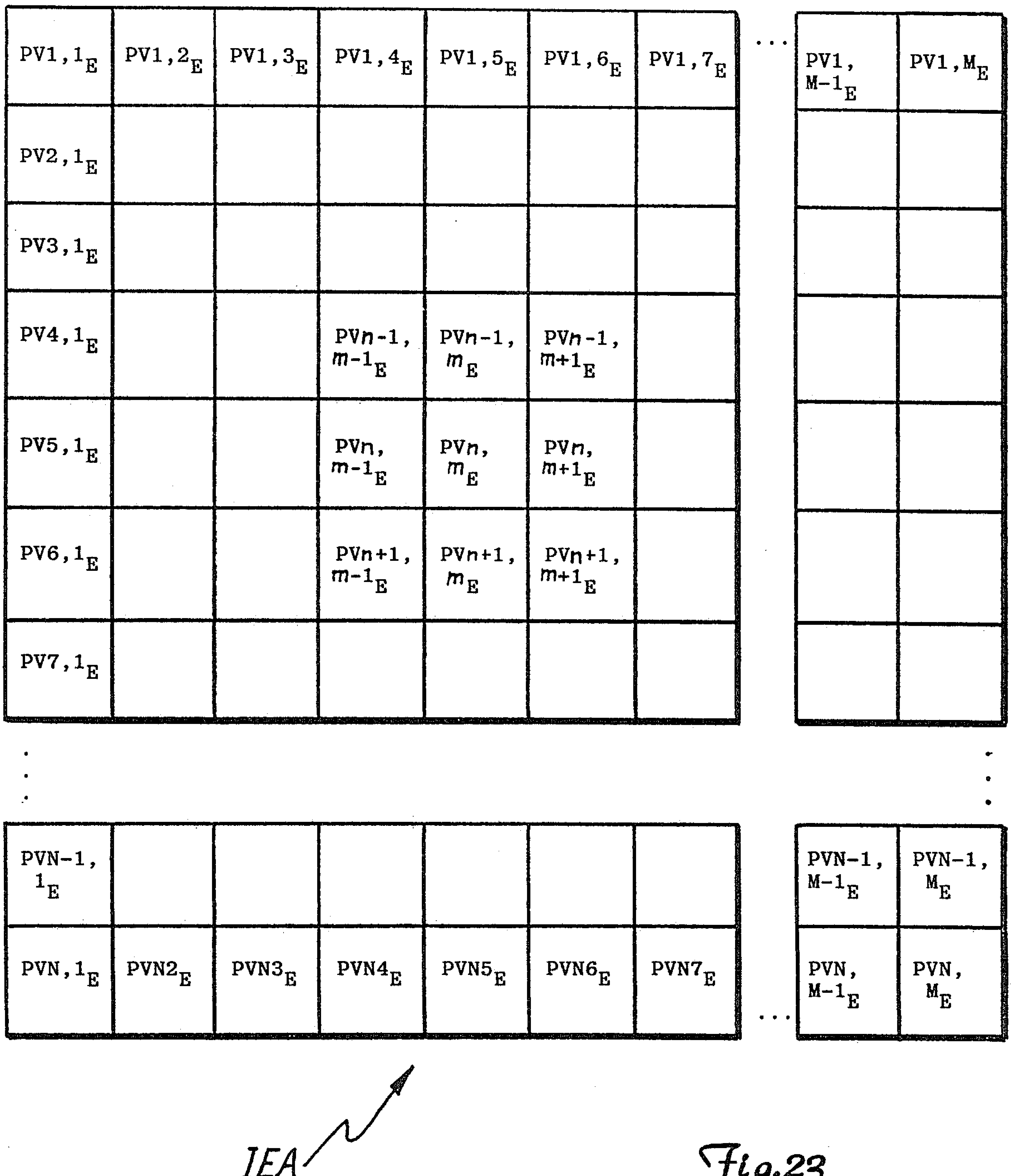
PV1,4N
PV1,5N
PV1,6N
PV1,7N
PV1, M-1N
PV1,MN
PV2,1N
PV2,2N
PV2,3N
PV3,1N
PV3,2N
PV3,3N
PV4,1N
PVn-1, m-1N
PVn-1, mN
PVn-1, m+1N
PV5,1N
PVn, m-1N
PVn, mN
PVn, m+1N
PV6,1N
PVn+1, m-1N
PVn+1, mN
PVn+1, m+1N
PV7,1N
PVN-1, 1N
PVN-1, M-1N
PVN-1, MN
PVN,1M
PVN2M
PVN3N
PVN4N
PVN5N
PVN6N
PVN7N
PVN, M-1N
PVN, MN
NAA

Fig.22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PV1,3E
PV1,4E
PV1,5E
PV1,6E
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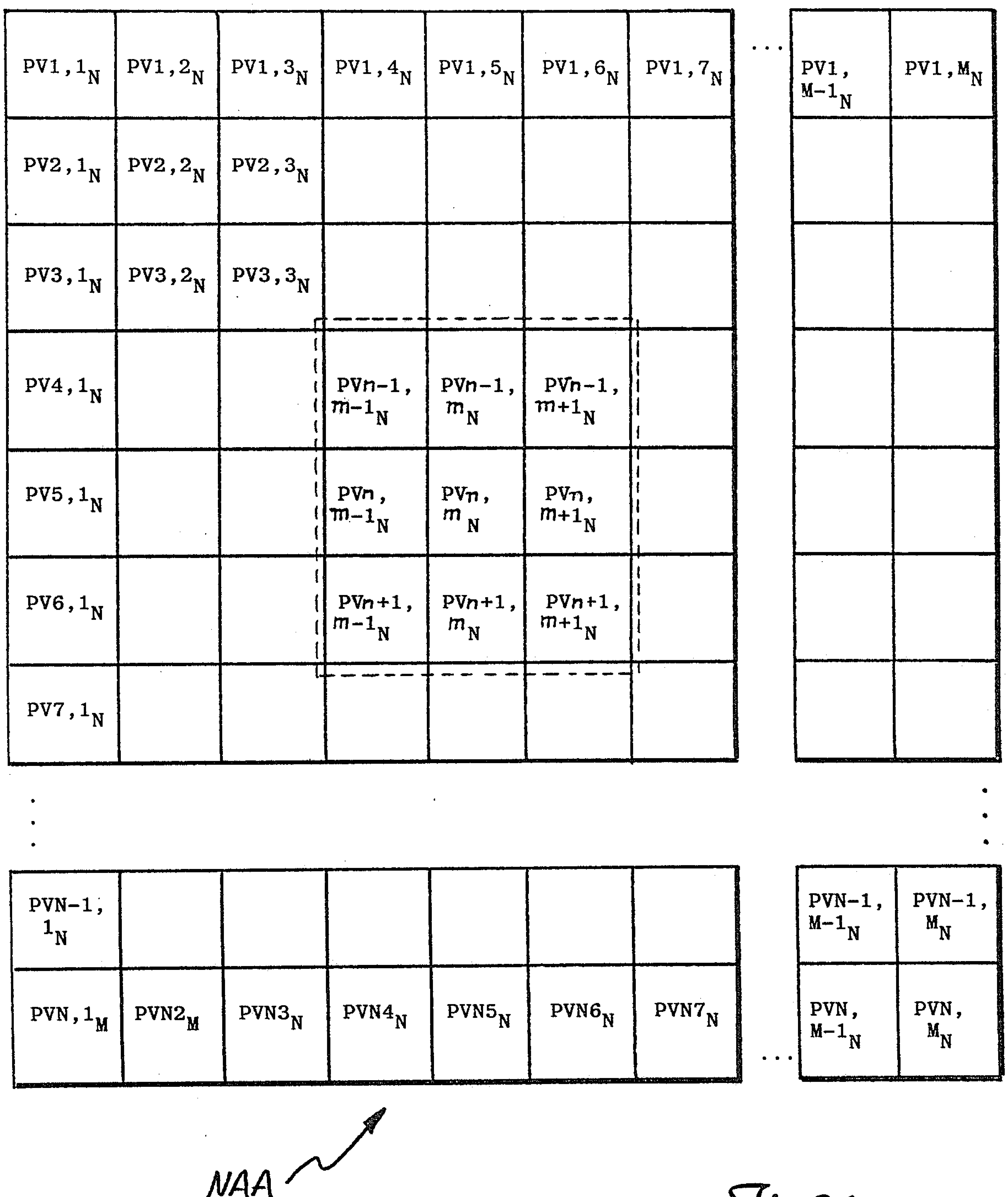
PV1, M-1E
PV1,ME
PV2,1E
PV3,1E
PV4,1E
PVn-1, m-1E
PVn-1, mE
PVn-1, m+1E
PV5,1E
PVn, m-1E
PVn, mE
PVn, m+1E
PV6,1E
PVn+1, m-1E
PVn+1, mE
PVn+1, m+1E
PV7,1E
PVN-1, 1E
PVN-1, M-1E
PVN-1, ME
PVN,1E
PVN2E
PVN3E
PVN4E
PVN5E
PVN6E
PVN7E
PVN, M-1E
PVN, ME
IEA

Fig.23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$PV1,2_N$
$PV1,3_N$
$PV1,4_N$
$PV1,5_N$
$PV1,6_N$
$PV1,7_N$
$PV1,M-1_N$
$PV1,M_N$
$PV2,1_N$
$PV2,2_N$
$PV2,3_N$
$PV3,1_N$
$PV3,2_N$
$PV3,3_N$
$PV4,1_N$
$PVn-1,m-1_N$
$PVn-1,m_N$
$PVn-1,m+1_N$
$PV5,1_N$
$PVn,m-1_N$
PVn,m_N
$PVn,m+1_N$
$PV6,1_N$
$PVn+1,m-1_N$
$PVn+1,m_N$
$PVn+1,m+1_N$
$PV7,1_N$
$PVN-1,1_N$
$PVN-1,M-1_N$
$PVN-1,M_N$
$PVN,1_M$
$PVN2_M$
$PVN3_N$
$PVN4_N$
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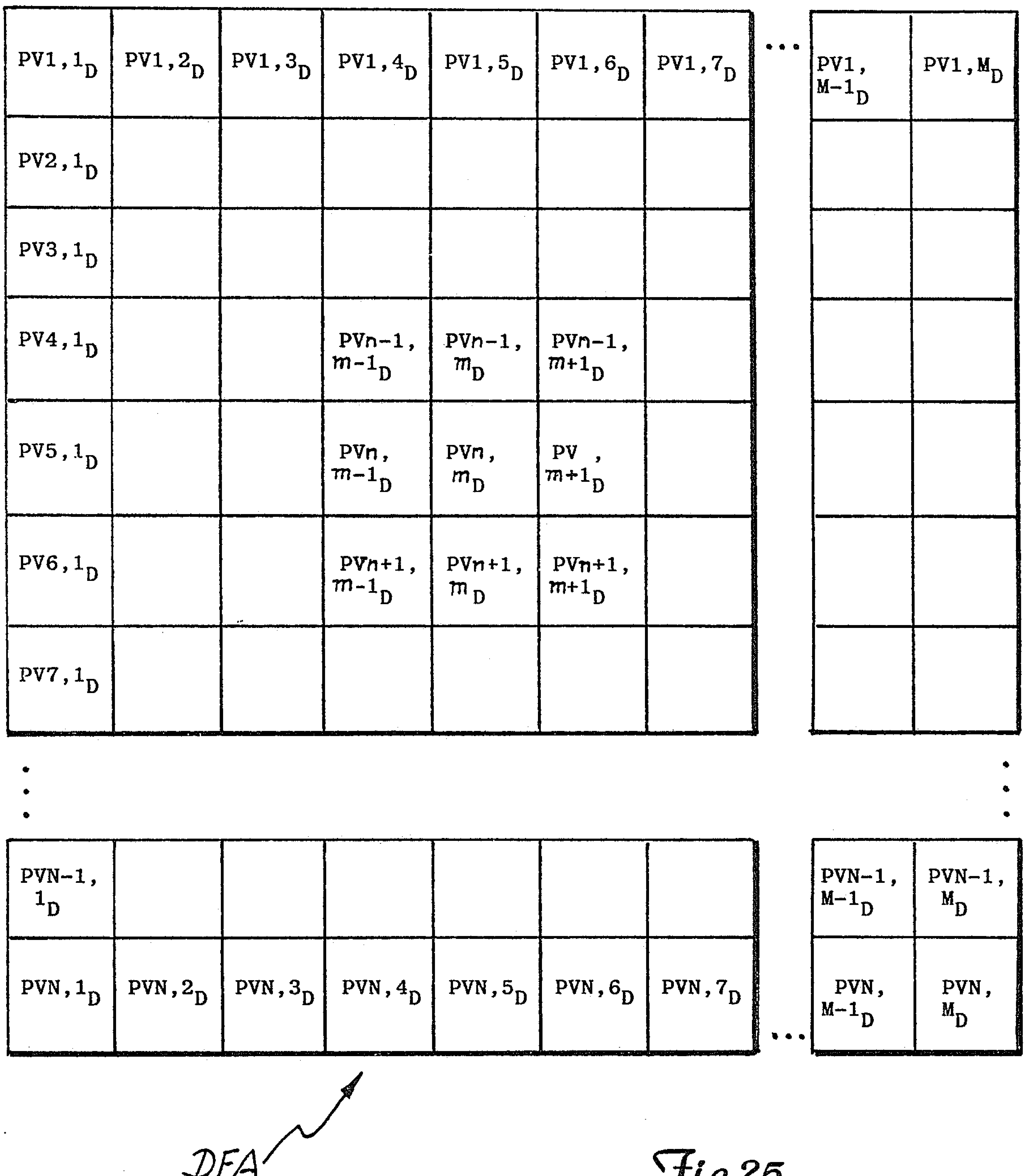
$PVN6_N$
$PVN7_N$
$PVN,M-1_N$
PVN,M_N
NAA

Fig.24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PV1,4D
PV1,5D
PV1,6D
PV1,7D
PV1, M-1D
PV1,MD
PV2,1D
PV3,1D
PV4,1D
PVn-1, m-1D
PVn-1, mD
PVn-1, m+1D
PV5,1D
PVn, m-1D
PVn, mD
PV , m+1D
PV6,1D
PVn+1, m-1D
PVn+1, mD
PVn+1, m+1D
PV7,1D
PVN-1, 1D
PVN-1, M-1D
PVN-1, MD
PVN,1D
PVN,2D
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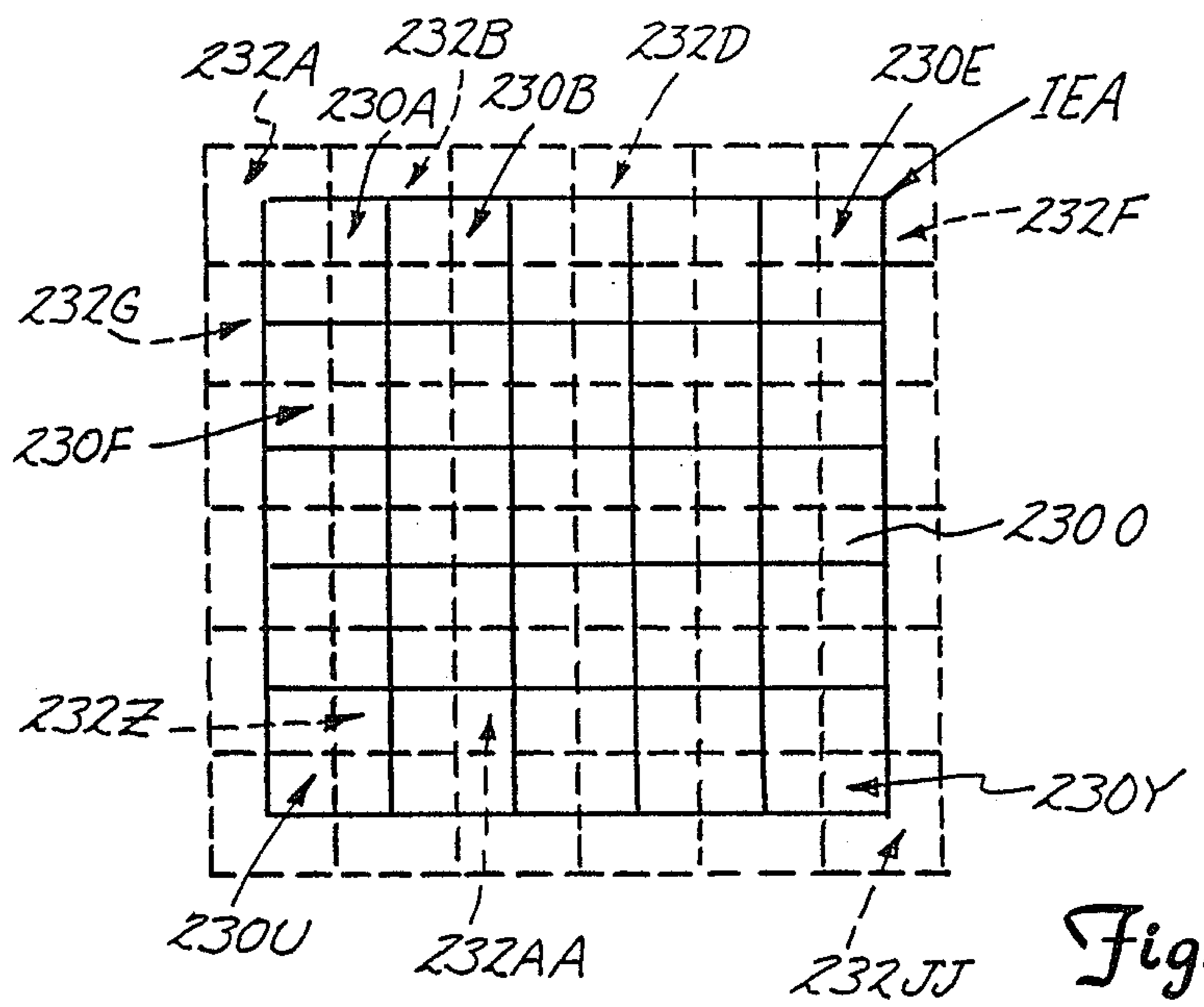
PVN,7D
PVN, M-1D
PVN, MD
DFA

Fig.25


232A
232B
232D
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230B
232F
232G
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232Z
230Y
230U
232AA
232JJ

Fig.26

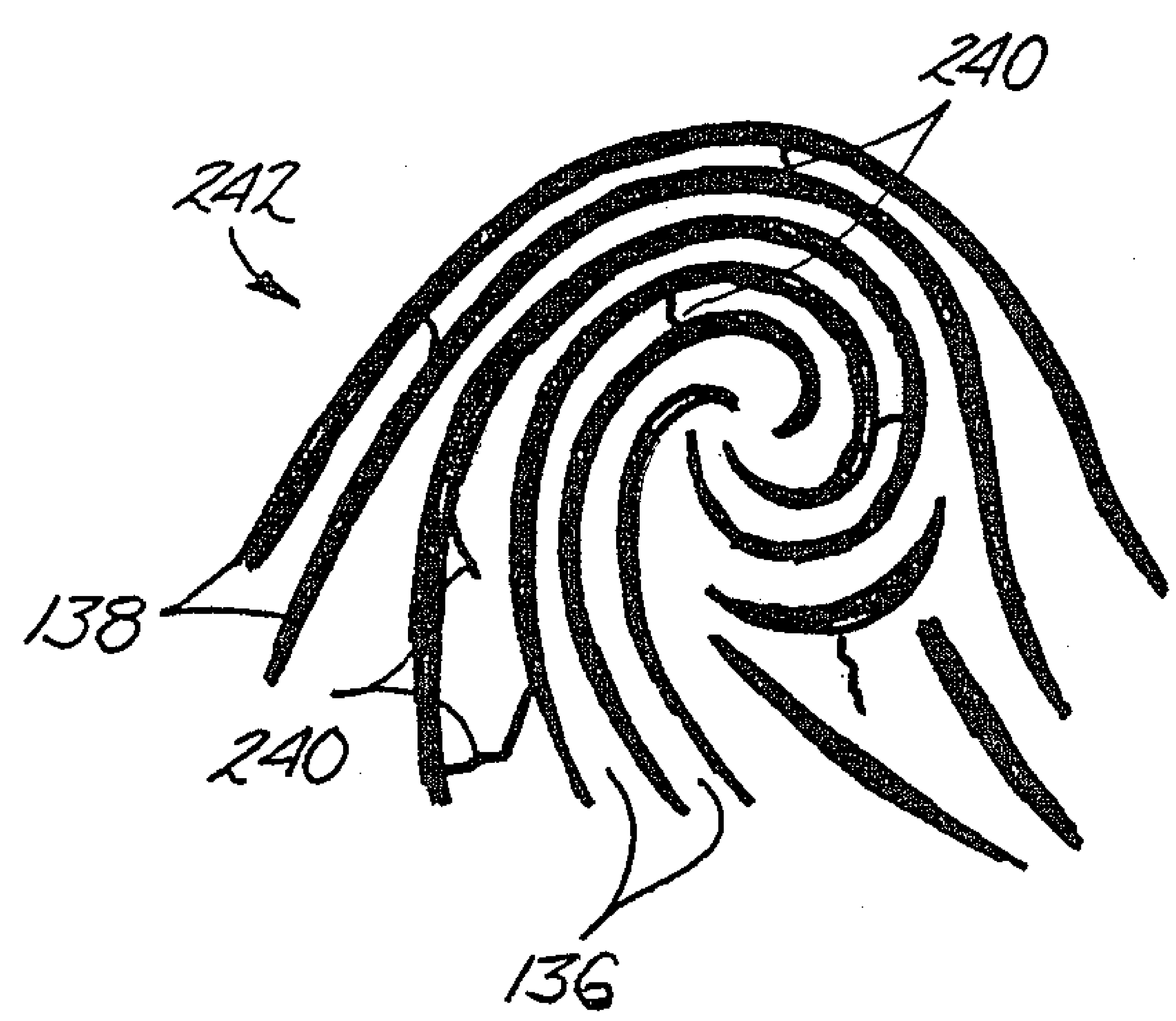
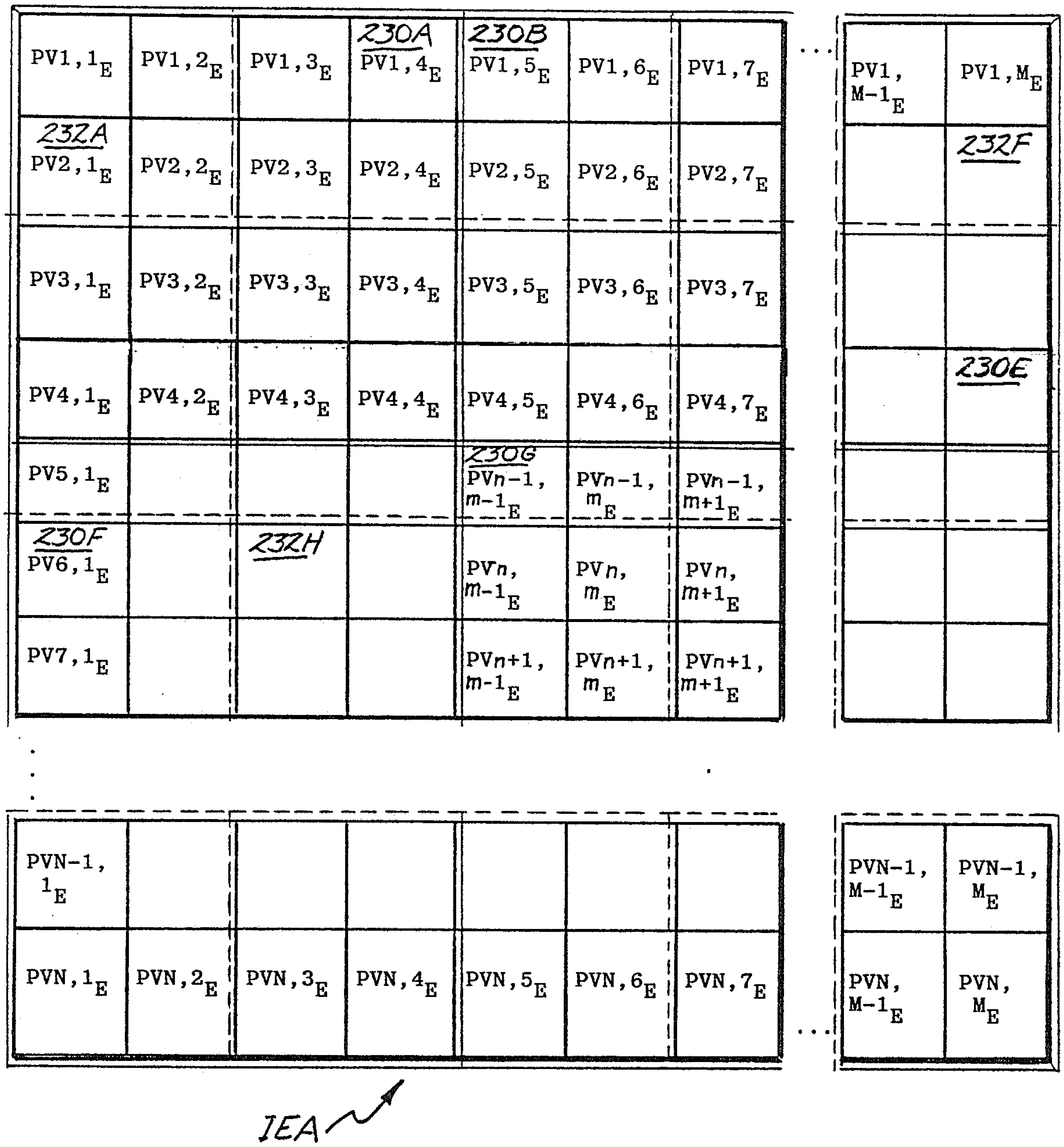

240
242
138
240
136

Fig.28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230B
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PV1,2E
PV1,3E
PV1,4E
PV1,5E
PV1,6E
PV1,7E
PV1, M-1E
PV1,ME
232A
PV2,1E
PV2,2E
PV2,3E
PV2,4E
PV2,5E
PV2,6E
PV2,7E
232F
PV3,1E
PV3,2E
PV3,3E
PV3,4E
PV3,5E
PV3,6E
PV3,7E
PV4,1E
PV4,2E
PV4,3E
PV4,4E
PV4,5E
PV4,6E
PV4,7E
230E
PV5,1E
230G
PVn-1, m-1E
PVn-1, mE
PVn-1, m+1E
230F
PV6,1E
232H
PVn, m-1E
PVn, mE
PVn, m+1E
PV7,1E
PVn+1, m-1E
PVn+1, mE
PVn+1, m+1E
PVN-1, 1E
PVN-1, M-1E
PVN-1, ME
PVN,1E
PVN,2E
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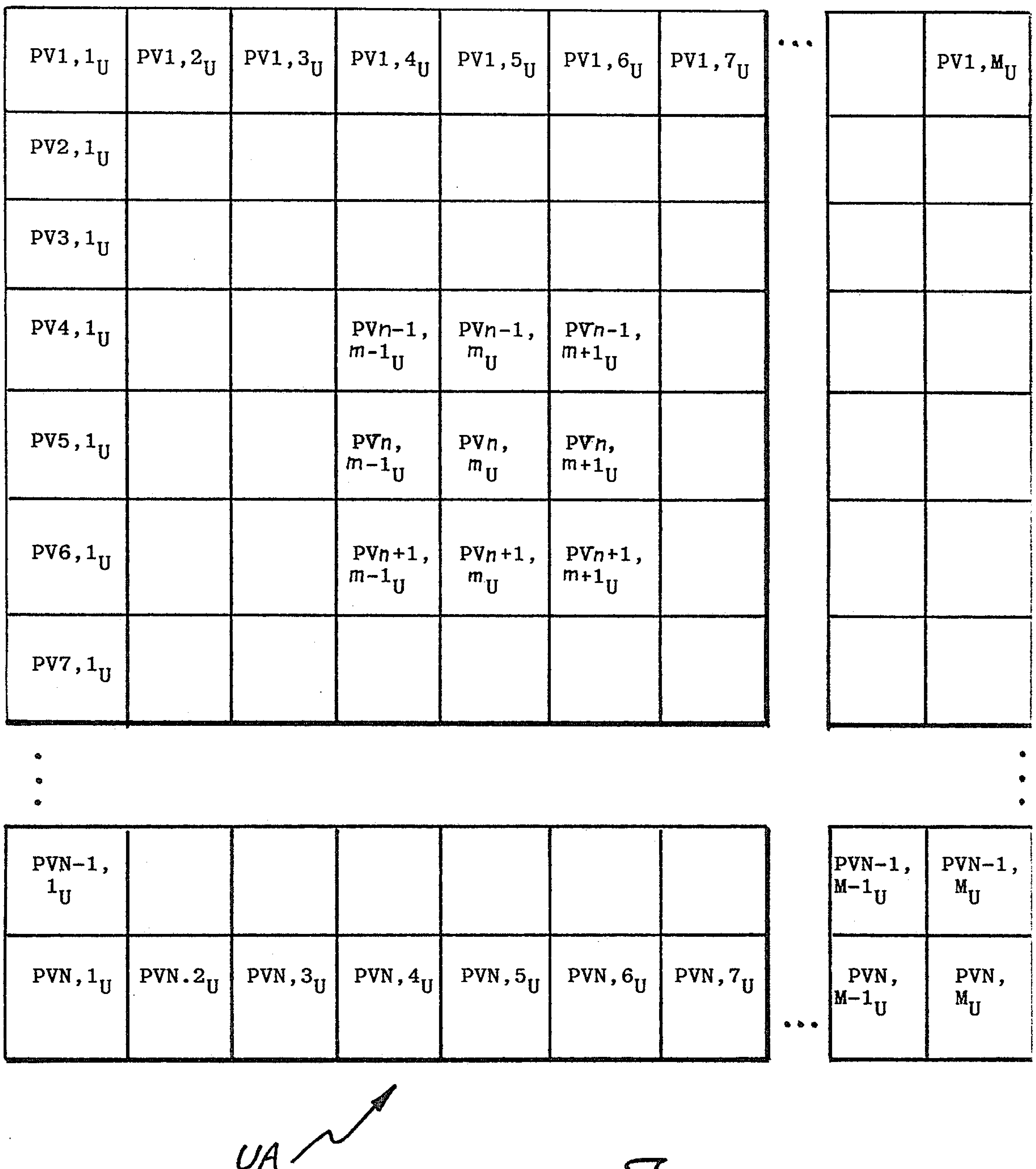
PVN,7E
PVN, M-1E
PVN, ME
IEA

Fig.27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PV1,3U
PV1,4U
PV1,5U
PV1,6U
PV1,7U
PV1,MU
PV2,1U
PV3,1U
PV4,1U
PVn-1, m-1U
PVn-1, mU
PVn-1, m+1U
PV5,1U
PVn, m-1U
PVn, mU
PVn, m+1U
PV6,1U
PVn+1, m-1U
PVn+1, mU
PVn+1, m+1U
PV7,1U
PVN-1, 1U
PVN-1, M-1U
PVN-1, MU
PVN,1U
PVN.2U
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PVN, MU
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Fig.29

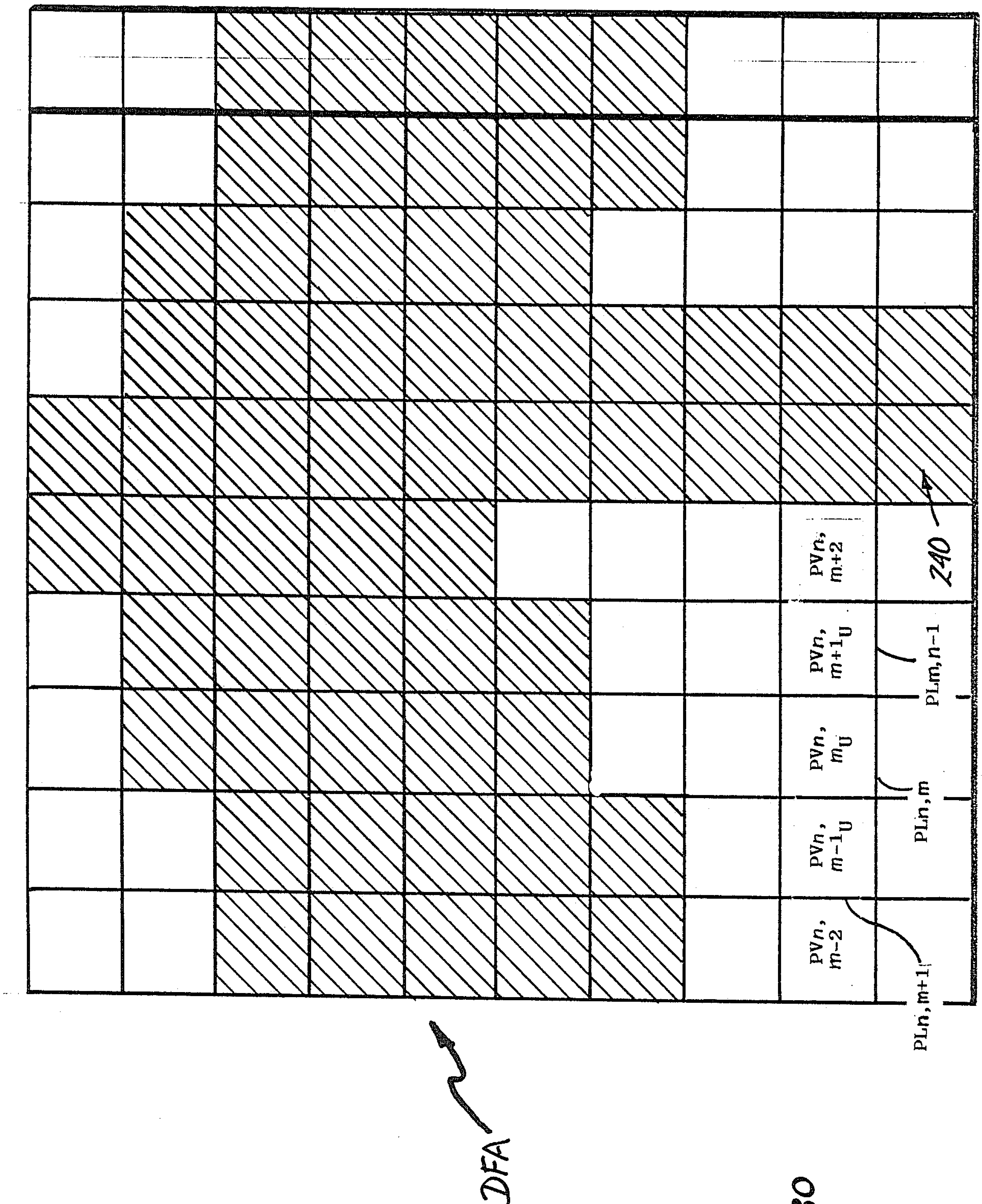
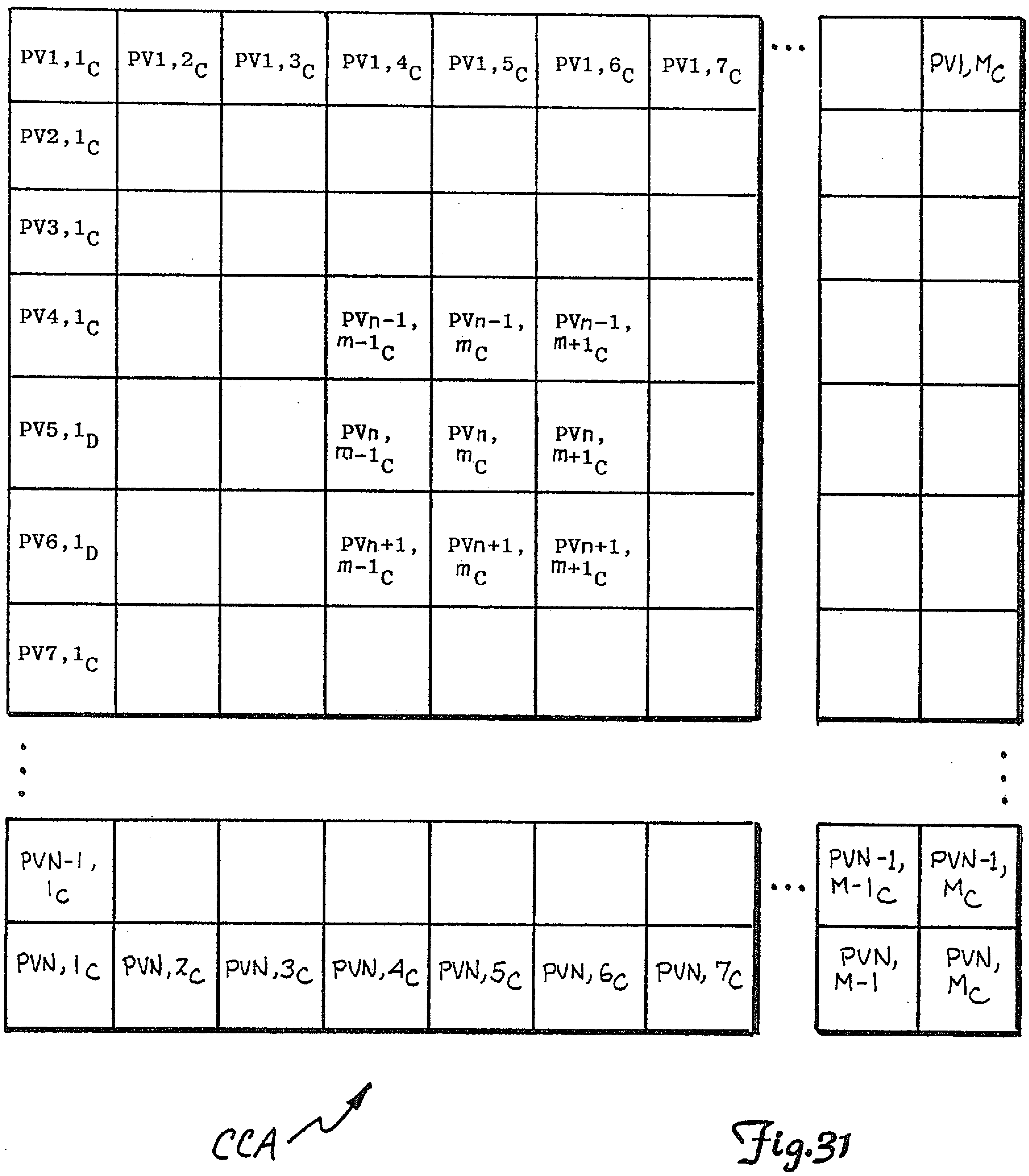


Fig.30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PV1,3C
PV1,4C
PV1,5C
PV1,6C
PV1,7C
PV1,MC
PV2,1C
PV3,1C
PV4,1C
PVn-1, m-1C
PVn-1, mC
PVn-1, m+1C
PV5,1D
PVn, m-1C
PVn, mC
PVn, m+1C
PV6,1D
PVn+1, m-1C
PVn+1, mC
PVn+1, m+1C
PV7,1C
PVN-1, 1C
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PVN,2C
PVN,3C
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PVN,5C
PVN,6C
PVN,7C
PVN, M-1
PVN, MC
CCA

Fig.31

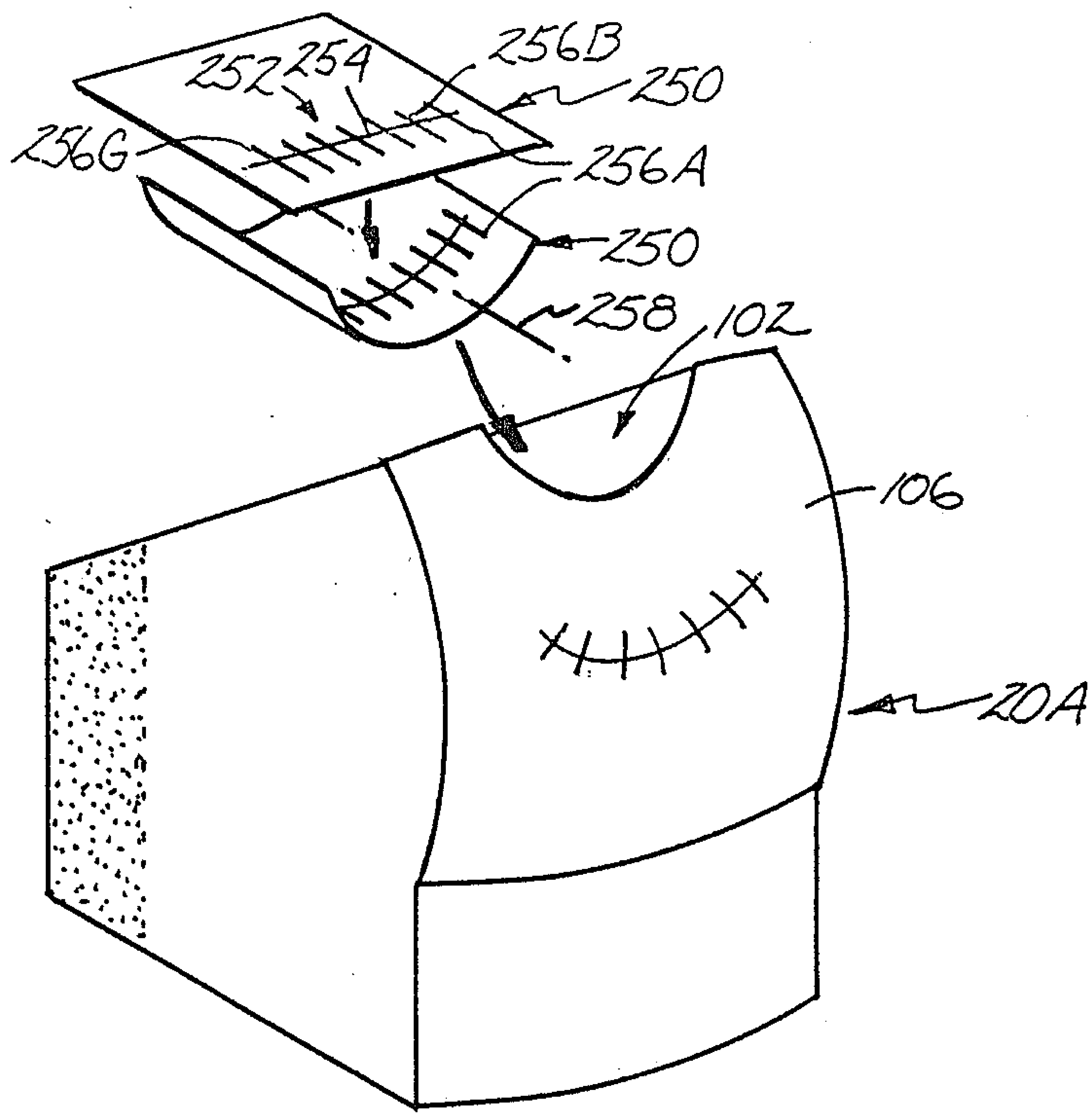

256B
252
254
250
256G
256A
250
258
102
106
20A

Fig.32

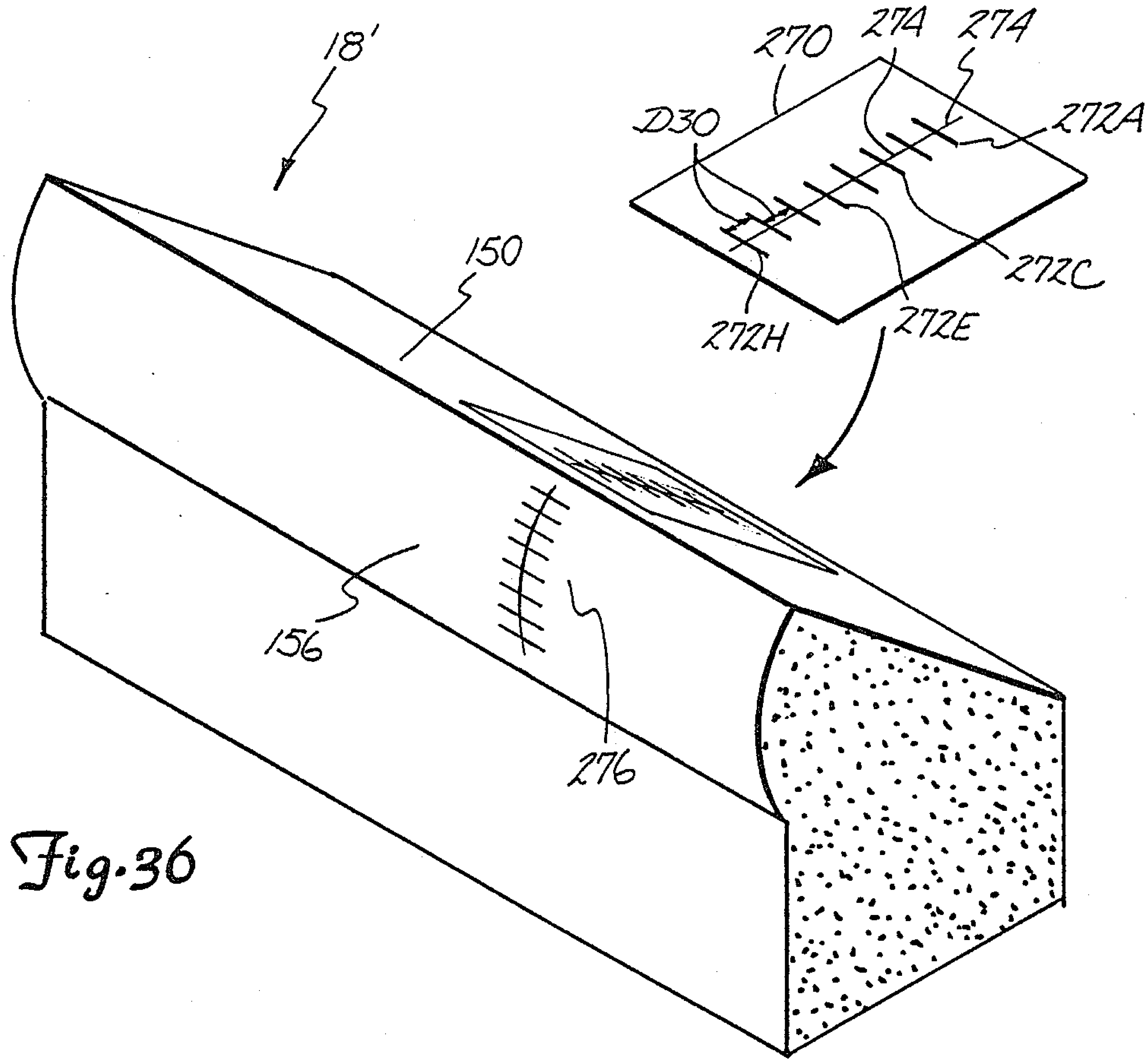

18'
270
274
274
D30
272A
150
272C
272H
272E
156
276

Fig.36

Fig.33

Curvature Correction Table	
OFF 1	7
OFF 2	7
OFF 3	6
OFF 4	6
OFF 5	5
OFF 6	5
OFF 7	4
OFF 8	4
OFF 9	3
OFF 10	3
. . .	. . .
OFF m	
⋮	
OFF M	

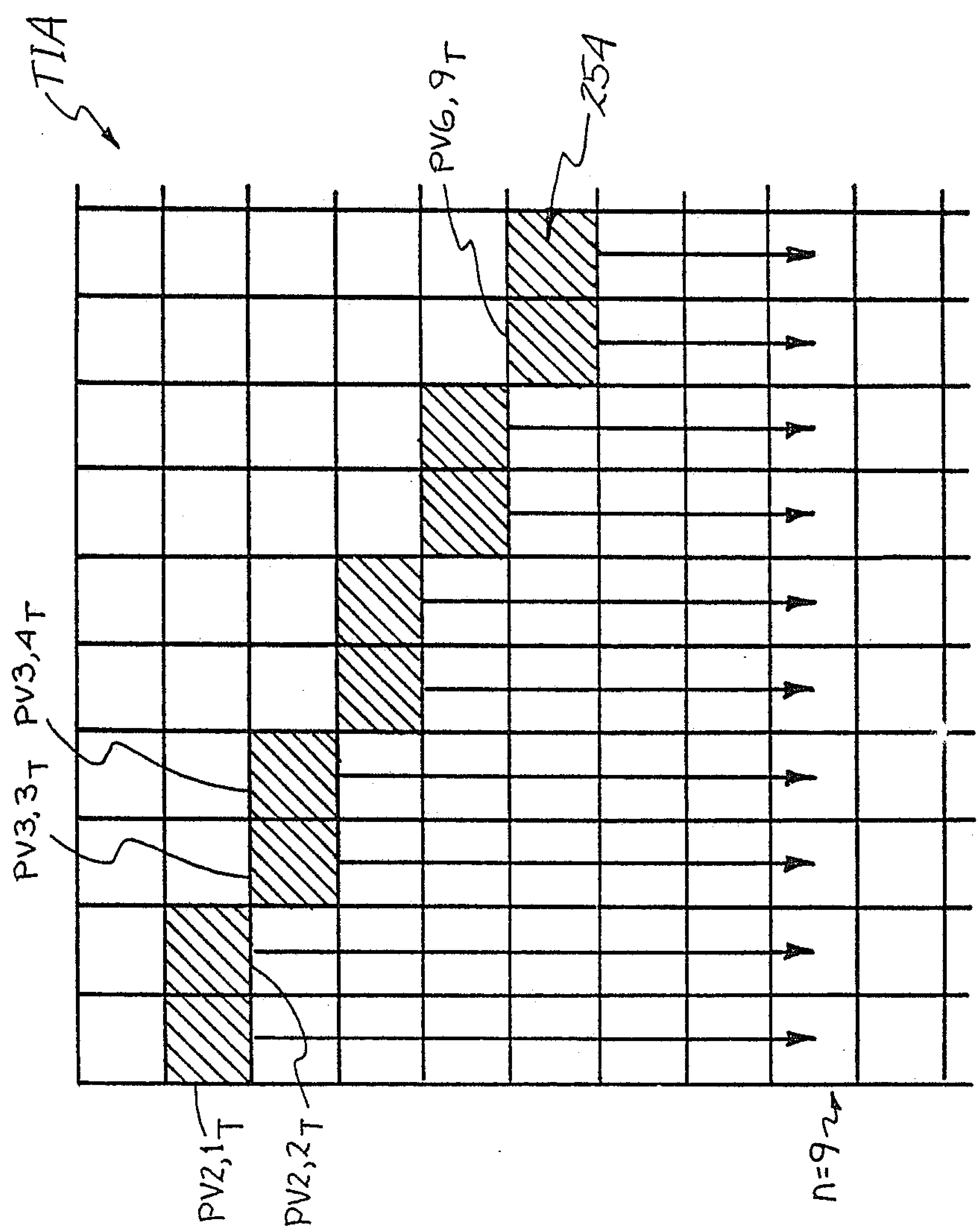


Fig.34

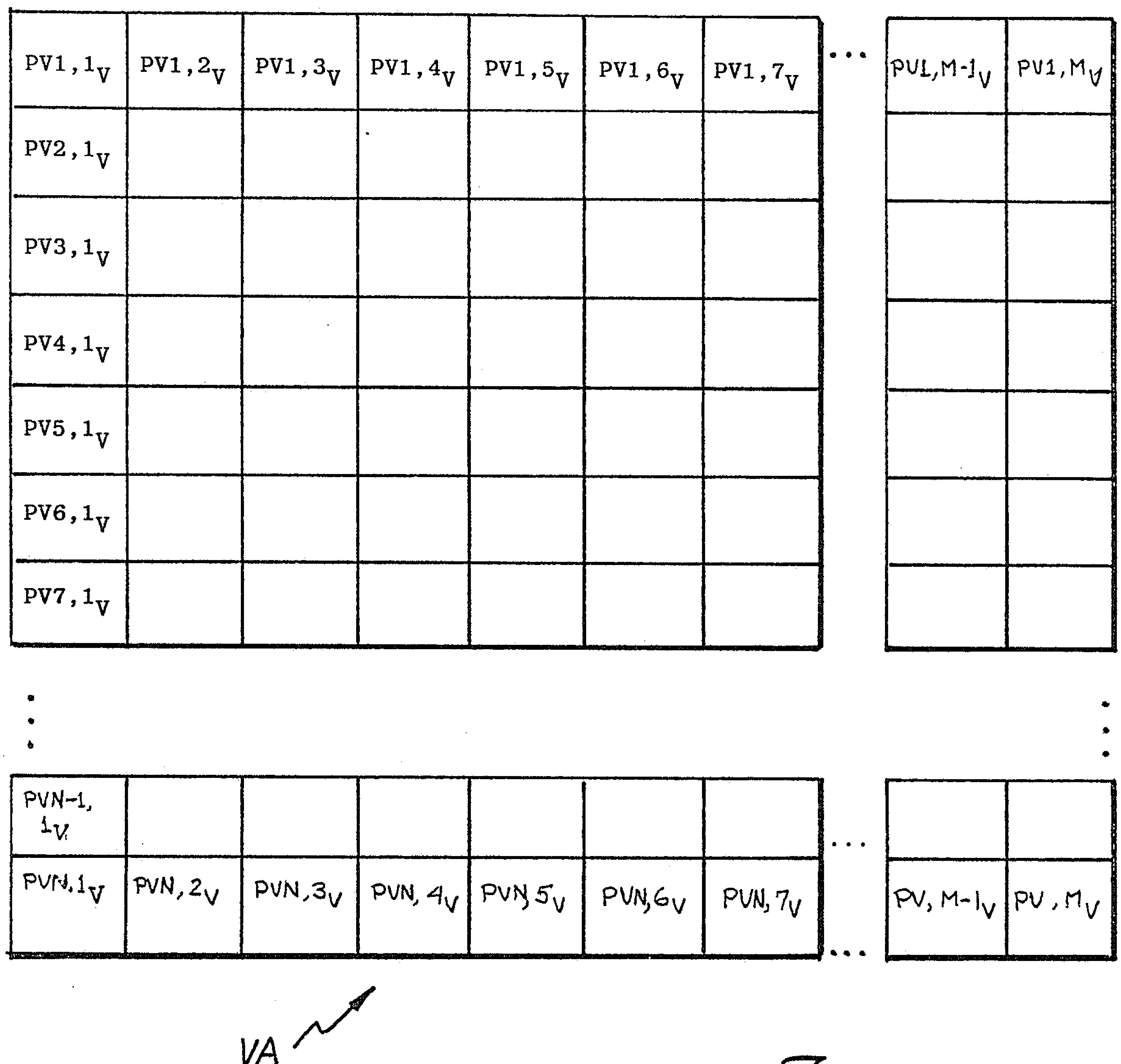

PV1,1V
PV1,2V
PV1,3V
PV1,4V
PV1,5V
PV1,6V
PV1,7V
PV1,M-1V
PV1,MV
PV2,1V
PV3,1V
PV4,1V
PV5,1V
PV6,1V
PV7,1V
PVN-1, 1V
PVN,1V
PVN,2V
PVN,3V
PVN,4V
PVN,5V
PVN,6V
PVN,7V
PV,M-1V
PV,MV
VA

Fig. 35

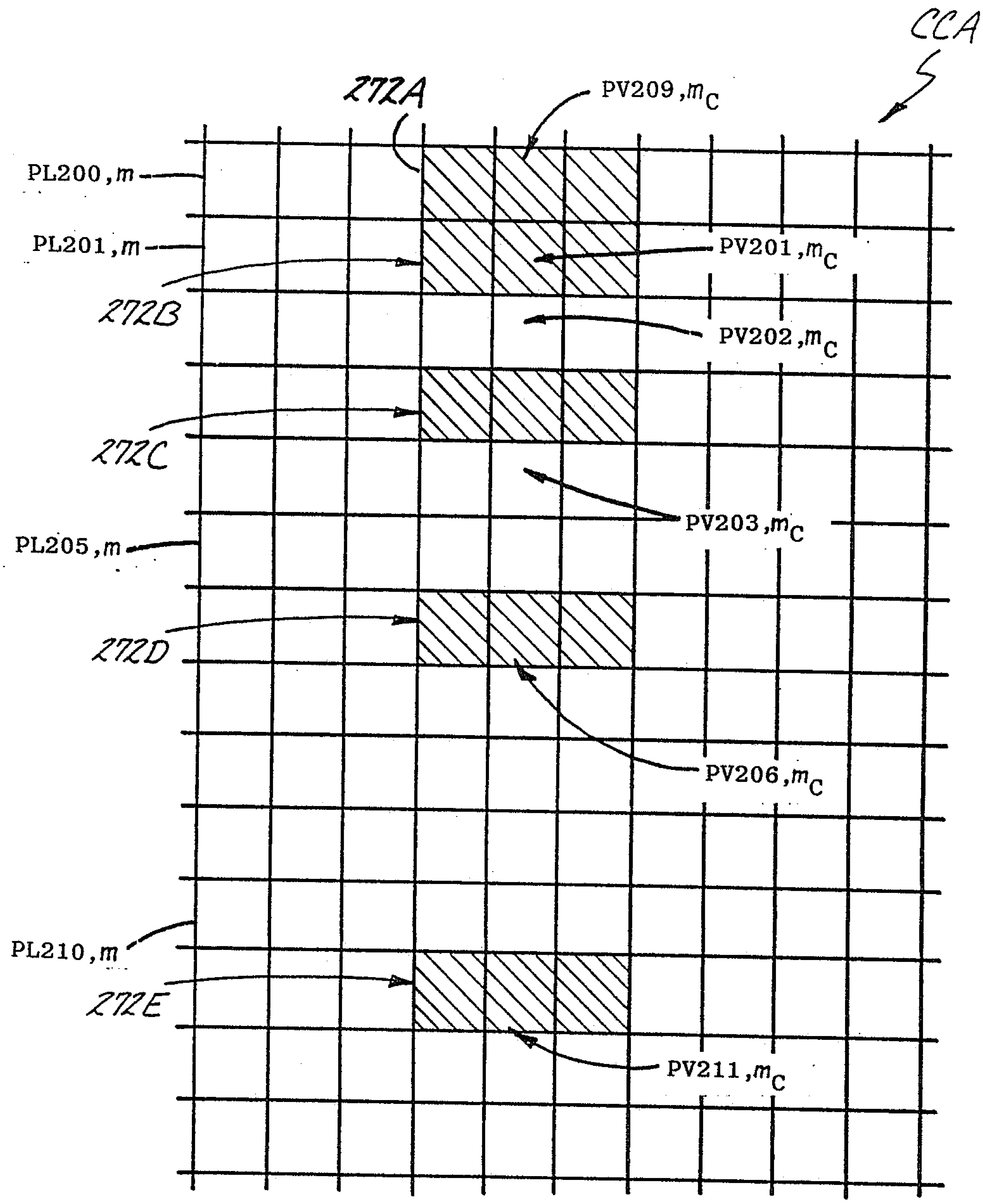

CCA
272A
PV209,m_C
PL200,m
PL201,m
PV201,m_C
272B
PV202,m_C
272C
PV203,m_C
PL205,m
272D
PV206,m_C
PL210,m
272E
PV211,m_C

Fig.37

HORIZONTALLY SCALED ARRAY HA	VERTICALLY SCALED ARRAY VA
$PVn,1_H$	PVMAX
$PVn,2_H$	PVMAX
⋮	⋮
$PVn,300_H$	$PVn,300_V$
$PVn,301_H$	$PVn,301_V$
$PVn,302_H$	$PVn,301_V$
$PVn,303_H$	$PVn,301_V$
$PVn,304_H$	$PVn,301_V$
$PVn,305_H$	$PVn,302_V$
$PVn,306_H$	$PVn,302_V$
$PVn,307_H$	$PVn,302_V$
$PVn,308_H$	$PVn,303_V$
$PVn,309_H$	$PVn,304_V$
$PVn,310_H$	$PVn,305_V$
$PVn,311_H$	$PVn,305_V$
$PVn,312_H$	$PVn,306_V$
$PVn,313_H$	$PVn,307_V$
$PVn,314_H$	$PVn,309_V$
$PVn,315_H$	$PVn,310_V$
$PVn,316_H$	$PVn,311_V$
⋮	⋮
$PVn,M-1_H$	PVMAX
PVn,M_H	PVMAX

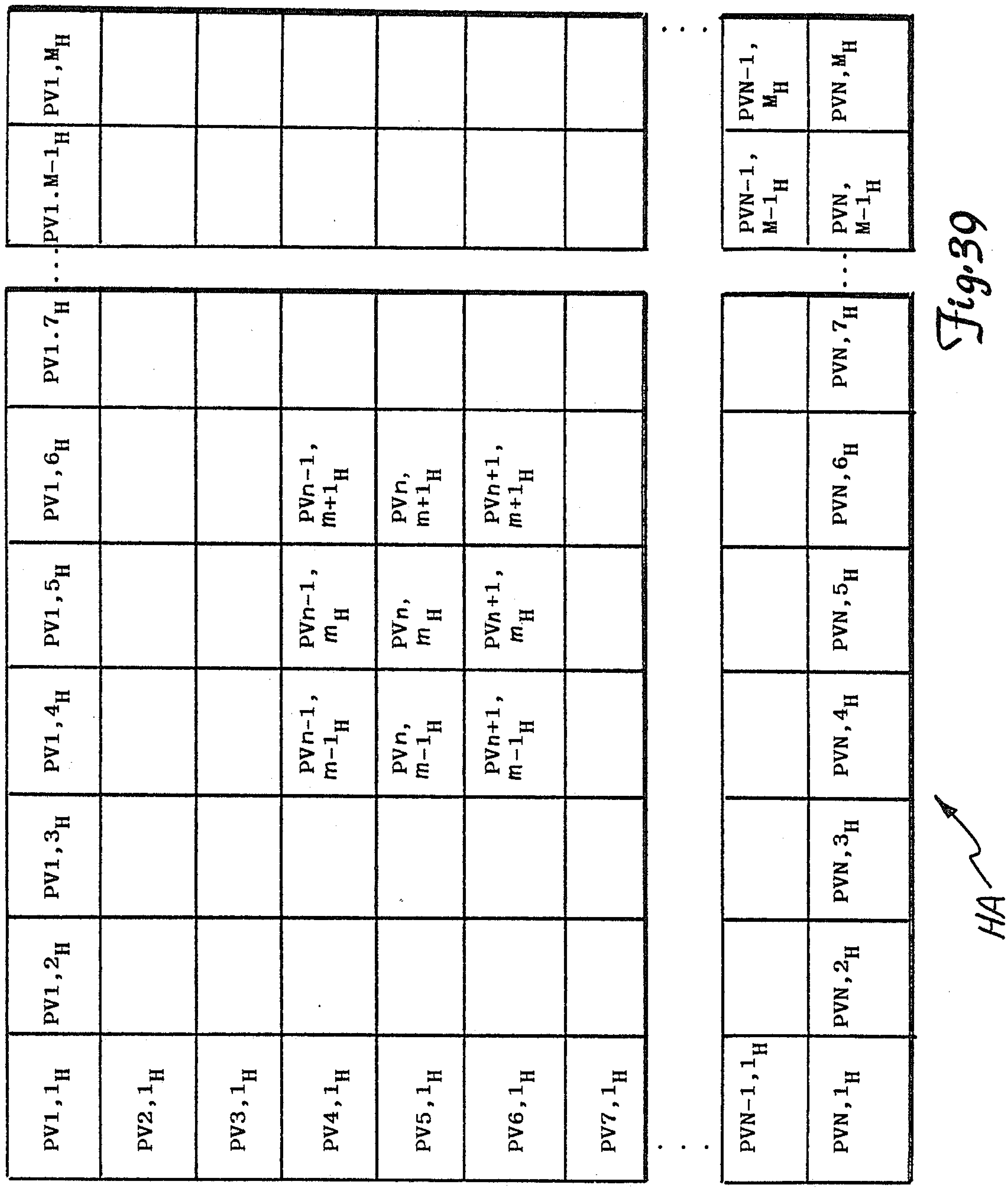
310

Fig. 40

VERTICALLY SCALED ARRAY VA	CURVATURE CORRECTED ARRAY CCA
$PV1,m_V$	PVMAX
$PV2,m_V$	PVMAX
⋮	⋮
$PV200,m_V$	$PV200,m_C$
$PV201,m_V$	$PV201,m_C$
$PV202,m_V$	$PV201,m_C$
$PV203,m_V$	$PV201,m_C$
$PV204,m_V$	$PV201,m_C$
$PV205,m_V$	$PV202,m_C$
$PV206,m_V$	$PV202,m_C$
$PV207,m_V$	$PV202,m_C$
$PV208,m_V$	$PV203,m_C$
$PV209,m_V$	$PV204,m_C$
$PV210,m_V$	$PV205,m_C$
$PV211,m_V$	$PV205,m_C$
$PV212,m_V$	$PV206,m_C$
$PV213,m_V$	$PV207,m_C$
$PV214,m_V$	$PV209,m_C$
$PV215,m_V$	$PV210,m_C$
$PV216,m_U$	$PV211,m_C$
⋮	⋮
$PVN-1,m_V$	PVMAX
PVN,m_V	PVMAX

280

Fig. 38



PV1,1H
PV1,2H
PV1,3H
PV1,4H
PV1,5H
PV1,6H
PV1.7H
PV1.M-1H
PV1,MH
PV2,1H
PV3,1H
PV4,1H
PV5,1H
PV6,1H
PV7,1H
PVn-1, m-1H
PVn-1, mH
PVn-1, m+1H
PVn, m-1H
PVn, mH
PVn, m+1H
PVn+1, m-1H
PVn+1, mH
PVn+1, m+1H
PVN-1,1H
PVN-1, M-1H
PVN-1, MH
PVN,1H
PVN,2H
PVN,3H
PVN,4H
PVN,5H
PVN,6H
PVN,7H
PVN, M-1H
PVN,MH
HA

Fig.39

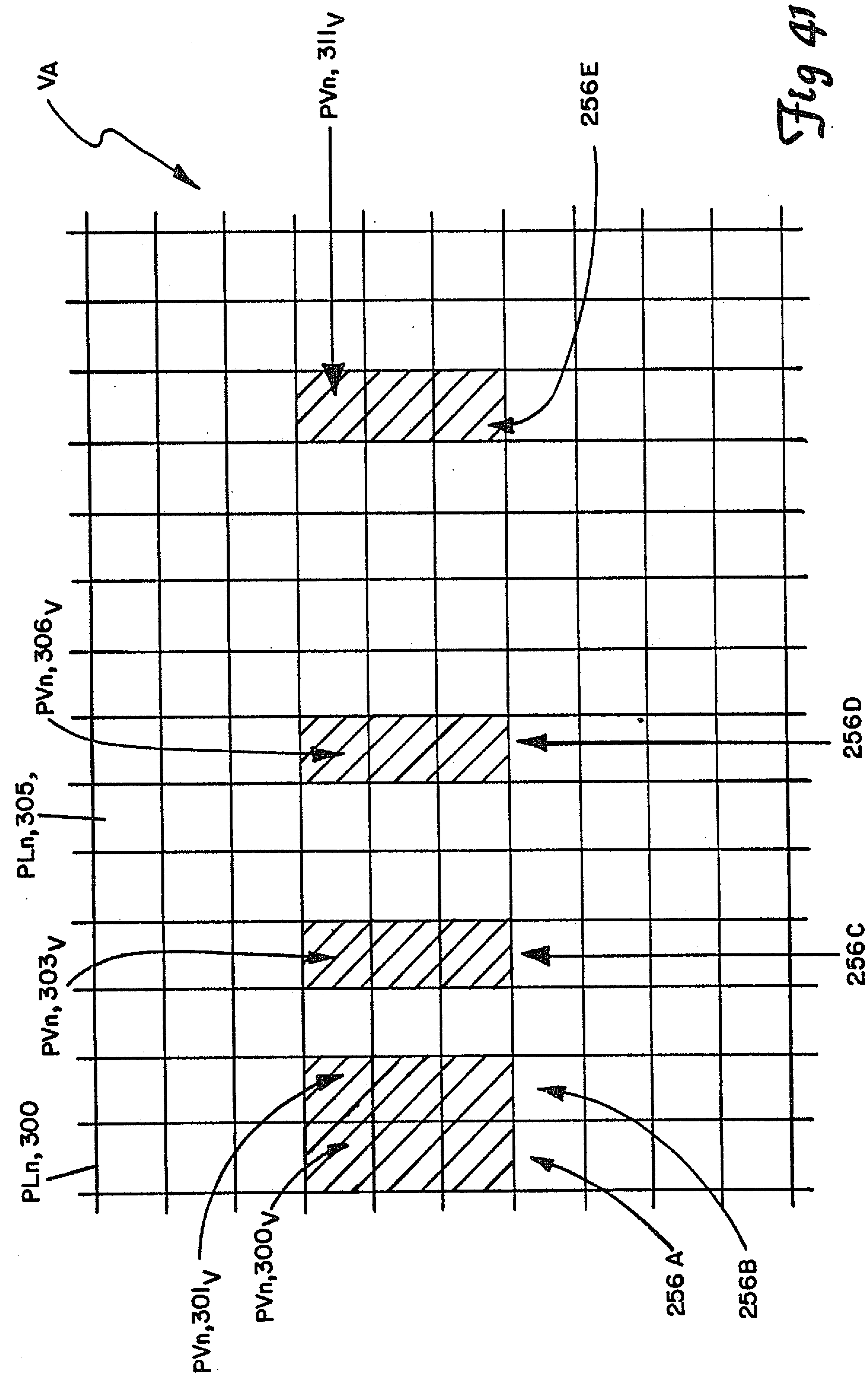

VA
PVn, 311v
256E
PVn,306v
PLn,305,
PVn,303v
PLn,300
PVn,301v
PVn,300v
256A
256B
256C
256D

Fig 41

300

TENPRINTER Data Capture System

1. Clear system for new card.
2. Start fingerprint capture.
3. Enter/change demographic function.
4. Print card.
5. Options.

Enter number, then press RETURN key:

Fig. 42

FIG 40

TENPRINTER Fingerprint Processing Choices

0. Exit.
1. Capture Prints.
2. Recapture Prints.
3. Options.

Enter number, then press RETURN key:

Fig. 46

FIG 41

Name: Last ______ First ______ Middle ______

Date of Birth (DOB) ______ Place of Birth ______

Sex ___ Race ___ Hgt ___ Wgt ___ Eyes ___ Hair ______

Aliases ______ Contributor (ORI) ______

Your no. (OCA) ______ FBI no. (FBI) ______

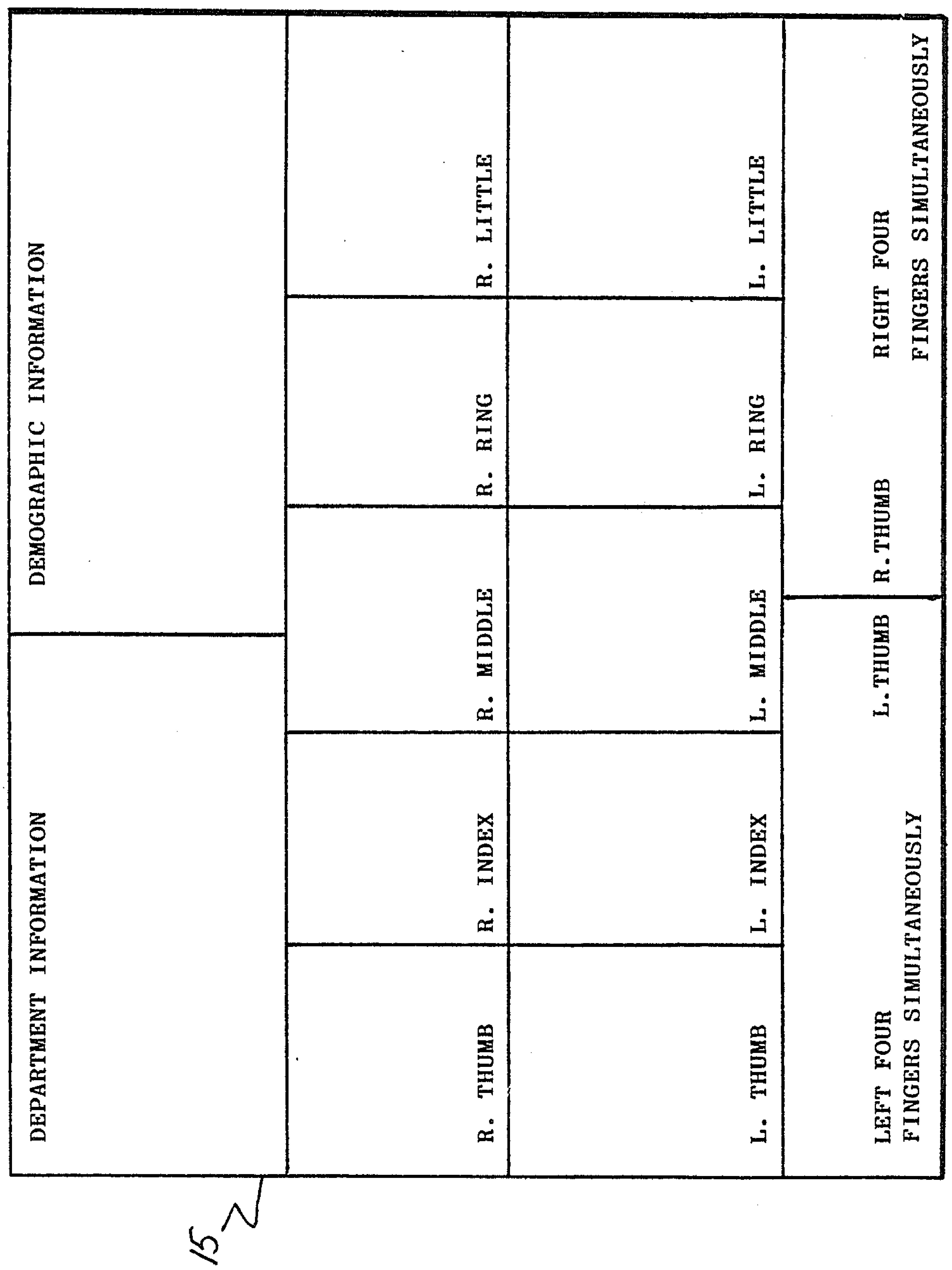
SID no. (SID) ______ Social Security no. (SOC) ______

Today's date ______ Date Arrested or Received (DOA) ______

Charge ______ Final Disposition ______

Fig. 45

Fig. 47


DEMOGRAPHIC INFORMATION
DEPARTMENT INFORMATION
R. LITTLE
R. RING
R. MIDDLE
R. INDEX
R. THUMB
L. LITTLE
L. RING
L. MIDDLE
L. INDEX
L. THUMB
RIGHT FOUR FINGERS SIMULTANEOUSLY
R. THUMB
L. THUMB
LEFT FOUR FINGERS SIMULTANEOUSLY
15

METHODS FOR DIGITALLY NOISE AVERAGING AND ILLUMINATION EQUALIZING FINGERPRINT IMAGES

Reference is hereby made to co-pending applications entitled Optical Fingerprinting System and Optical Devices for Providing Fingerprint Images, filed on even date herewith.

BACKGROUND OF THE INVENTION

1. Field of the Invention.

The present invention relates to computer processing of fingerprint images

2. Description of the Prior Art.

Over the years, the most commonly used technique for obtaining fingerprints has been to apply ink to the tip of individual fingers and roll the inked fingertip at an appropriate location on an applicant card to produce the "rolled" fingerprint. Plain or "slap" prints, which are the simultaneous fingerprinting of the index, middle, ring, and little fingers of a hand, are taken by inking the tips of these fingers and simultaneous pressing the inked fingertips on the applicant card at the appropriate location. While these inking procedures will usually provide satisfactory images, they have their drawbacks. The inking procedure is messy. Several attempts are often required in order to obtain an acceptable fingerprint. Perhaps even a bigger drawback of this system is that the printed images are not easily adaptable to computerized storage and processing techniques, inhibiting cooperation and fingerprint data transfer between various police agencies.

Optical fingerprinting systems which optically generate fingerprint images are also in use. Several such optical fingerprinting systems are disclosed in the U.S. Pat. Nos. to Becker 3,482,498, McMahon 3,975,711, White 3,200,701, Schiller 4,544,267 and Marcus 4,553,387. However, for a variety of reasons, systems such as these have not gained widespread acceptance.

Due to the compound curved nature of the fingerprint on a finger, it is difficult to optically obtain an image corresponding to a rolled fingerprint. The Schiller U.S. Pat. No. 4,544,267 discloses an apparatus in which a finger pressed against a platen provides a fingerprint object which is scanned by an interrogating beam of collimated light that is linearly displaced across the platen thereby maintaining a constant angle between the interrogating light beam and the plane of the object being scanned. The Marcus U.S. Pat. No. 4,553,837 discloses finger processing apparatus which includes a cylindrical-segment platen which supports a finger. Optical scanning equipment scans the circumference of the platen in such a manner that the angle of incidence of a light beam on the fingerprint object remains constant. The Becker U.S. Pat. No. 3,482,498 discloses several embodiments of an optical apparatus for producing a rolled fingerprint image, both of which utilize a prism having a totally reflecting surface. The embodiment shown in FIG. 1*a* utilizes a plurality of prisms and light sources, and produces only an approximation of the ball and side ridges. The embodiment shown in FIGS. 2 and 3 utilize a mechanical system actuated by a rolling finger to move and position a light source.

While the fingerprinting systems disclosed in the Schiller and Marcus patents, and the second embodiment disclosed in the Becker patent, may be capable of optically providing a rolled fingerprint image, these systems are less than wholly desirable. Perhaps most important, it is not possible to review the image being captured in real-time to determine whether or not critical information required for classification is being captured. Furthermore, the mechanical aspects of these systems, are relatively complicated. As a result, maintaining focus during the time required to obtain the entire rolled fingerprint image can be difficult. Although the fingerprint image produced by the first embodiment of the invention disclosed in the Becker patent provides an image in real-time, this image only approximates the rolled fingerprint image.

Prisms such as those disclosed in the McMahon U.S. Pat. No. 3,975,711 and the White U.S. Pat. No. 3,200,701 utilize the optical principle of total internal reflection to produce a fingerprint image. As such, the "plane" of the fingerprint must be imaged at an observation angle which is not perpendicular to the plane. Vertical scale errors, or distortions of distances on the fingerprint image from their true distances along a Y-axis which is generally parallel to a longitudinal axis of the finger, are therefore inherent. When the surface of the prism on which the finger is inserted is grooved as illustrated in the McMahon patent, horizontal scale errors which are distance distortions on the fingerprint image from true distances along a X-axis generally perpendicular to the longitudinal axis of the finger on the fingerprint, are also inherent. Furthermore, curvature errors are also produced. As a result of the vertical and horizontal scale errors, and the curvature errors inherent in the use of a grooved total internal reflection prism such as that shown in McMahon, the fingerprint image provided thereby is severely distorted from a true rolled fingerprint of the same finger.

Prisms which have grooved finger receiving surfaces such as those disclosed in the McMahon patent will not provide optimum surface contact between the surface of a finger and therefore its fingerprint, and the prism. Portions of the fingerprint which it may be desired to obtain will therefore be lost. Illumination of the fingerprint through prisms such as that shown in the McMahon patent is often unequal, resulting in an image which has varying intensities throughout its area. Furthermore the contrast between ridges and valleys in the fingerprint image produced by these prisms is generally relatively low.

Many police departments including the FBI require both plain or slap fingerprint images and individual rolled fingerprint images as part of their standard fingerprinting process. Prior art optical fingerprinting systems, however, are incapable of optically generating both individual rolled fingerprints and slap fingerprint images.

It is evident that there is a continuing need for improved optical fingerprinting systems. A system having the capability of capturing both slap and rolled fingerprint images would be especially desirable. An operator should be able to easily interface with the system, and observe in real-time the quality of the fingerprint image before it is captured. A system which can capture fingerprints from fingers of varying sizes would also be useful.

It is also evident that there is room for improvement in the prisms utilized by optical fingerprinting systems. Grooves in these prisms should be contoured in a manner which permits optimum contact between the fingerprint and grooved surface. A prism which can capture slap fingerprint images is also needed. A prism which reduces horizontal and vertical scale errors, as well as curvature errors, would also be welcomed. Furthermore, a prism which produces a high contrast fingerprint image is also needed. Other techniques which can correct for vertical and horizontal scale errors, and curvature errors so as to produce an enhanced fingerprint image would also be desirable properties of an optical fingerprinting system.

SUMMARY OF THE INVENTION

The present invention is a method of operating programmable computing means to enhance fingerprint images. Using a noise average method, input pixel values of an array of input pixel values characteristic of the fingerprint image are processed to produce a noise averaged array of pixel values characteristic of a noise averaged image. An input array of pixel value characteristic of a fingerprint image is received. Noise averaging subarrays of input pixel values are selected. Each subarray includes an input pixel value to be noise averaged, and a plurality of input pixel values adjacent the pixel value to be noise averaged. Noise averaged pixel values are generated as a function of a weighted average of the input pixel values in the noise averaging subarrays. The noise averaged pixel values are then stored as an array of noise averaged pixel values characteristic of the image.

Using an illumination equalizing method, input pixel values of an array of input pixel values characteristic of a fingerprint image are processed to produce an illumination equalized array of pixel values characteristic of an illumination equalized image. An array of input pixel values characteristic of a fingerprint image is received. Equalizing subarrays of input pixel values are selected. Each subarray includes an input pixel value to be illumination equalized. Subarray average values are generated as a function of the pixel values within the equalizing subarrays. The subarray average values are subtracted from the corresponding pixel values being equalized to generate pixel difference values. A predetermined constant is added to the pixel difference values to generate intermediate illumination equalized pixel values. If intermediate illumination equalized pixel values are less than a predetermined minimum pixel value, the corresponding illumination equalized pixel values are set equal to the minimum pixel value. If intermediate illumination pixel values are greater than or equal to the minimum pixel value, and less than or equal to a predetermined maximum pixel value, the corresponding illumination equalized pixel values are set equal to the corresponding intermediate illumination equalized pixel values. If the intermediate illumination equalized pixel values are greater than the maximum pixel value, the corresponding illumination equalized pixel values are set equal to the maximum pixel value.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates elements of an optical fingerprinting system in accordance with the present invention.

FIG. 2 is a view looking into the top of the optics/processor unit shown in FIG. 1.

FIG. 3A is a side view of the optics subsystem shown in FIG. 2, illustrating the optical propagation of fingerprint images from the finger prism to the camera when the slap/image selection optics is positioned at its finger image position.

FIG. 3B is a side view of the optics subsystem shown in FIG. 2 illustrating the optical propogation of fingerprint images from the slap prism to the camera when the slap/image selection optics is positioned at its slap image position.

FIG. 4 is a detailed perspective view of the lens trolley shown in FIG. 2.

FIG. 5 is a detailed view of the fastening assembly shown in FIG. 2.

FIG. 6 is a perspective view of an individual finger prism shown in FIG. 2.

FIG. 7 is a sectional view of the finger prism shown in FIG. 6.

FIG. 8 is a rear view of the finger prism shown in FIG. 6.

FIG. 9 is a side view of the finger prism shown in FIG. 6.

FIG. 10 is a top view of the finger prism shown in FIG. 6.

FIG. 11 is a bottom view of the finger prism shown in FIG. 6.

FIG. 12 is a graphic representation of the optical properties of the finger prism shown in FIG. 6, when a finger is not positioned within its groove.

FIG. 13 is a graphic representation of the optical properties of the prism shown in FIG. 6, when a finger is positioned within its groove.

FIG. 14 is a detailed view of a portion of the prism and finger shown in FIG. 13, graphically illustrating the optical properties of the prism in conjunction with a finger positioned thereon.

FIG. 15 is a graphic representation of a finger illustrating various characteristics of a fingerprint thereon.

FIG. 16 is a perspective view of an alternative embodiment of the slap print prism shown in FIG. 2.

FIG. 17 is a side view of the slap print prism shown in FIG. 16.

FIG. 18 is a perspective view of the slap print prism shown in FIG. 2.

FIG. 19 is a side view of the slap print prism shown in FIG. 18.

FIG. 20 is a block diagram representation of the processor subsystem of the optics/processor unit shown in FIG. 1, and illustrating its interconnection to other electrical elements of the fingerprinting system.

FIG. 21 is a graphic representation of an image array of image pixel values generated by the frame digitizer shown in FIG. 20.

FIG. 22 is a graphic representation of a noise averaged array of noise averaged pixel values generated by the processor subsystem shown in FIG. 20.

FIG. 23 is a graphic representation of an illumination equalized array of illumination equalized pixel values generated by the processor subsystem shown in FIG. 20.

FIG. 24 is a graphic representation of the noise averaged array, illustrating a subarray of pixel values utilized by the processor subsystem to generate the illumination equalized array.

FIG. 25 is a graphic representation of a directional filtered array of directional filtered pixel values produced by the processor subsystem shown in FIG. 20.

FIG. 26 is a graphic representation of an illumination equalized array illustrating the regular and offset subarrays utilized by the processor subsystem shown in FIG. 20 to produce the directional filtered array.

FIG. 27 is a detailed graphic representation of an illumination equalized array such as that shown in FIG. 26, illustrating the regular and offset subarrays utilized by the processor subsystem shown in FIG. **20** to produce the directional filtered array.

FIG. **28** is a graphic representation of a fingerprint image showing artifacts or hairs therein.

FIG. **29** is a graphic representation of an unhaired array of unhaired pixel values produced by the processor subsystem shown in FIG. **20**.

FIG. **30** is a graphic representation of a directional filtered array illustrating a portion of a fingerprint image having an artifact or hair therein.

FIG. **31** is a graphic representation of a curvature corrected array of curvature corrected pixel values generated by the processor subsystem shown in FIG. **20**.

FIG. **32** is a view illustrating a template having a pattern of indicia thereon, and an image of the pattern of indicia when the template is positioned on the finger prism shown in FIG. **6**.

FIG. **33** is a qraphic repesentation of a curvature correction table of curvature correction data generated and used by the processor subsystem shown in FIG. **20** to produce the curvature corrected array shown in FIG. **31**.

FIG. **34** is a graphic representation of a template image array of template image pixel values generated by the processor subsystem shown in FIG. **20** and representing an image of the pattern of indicia shown in FIG. **32**.

FIG. **35** is a graphic representation of a vertically scaled array of vertically scaled pixel values generated by the processor subsystem shown in FIG. **20**.

FIG. **36** is a view illustrating a template having a pattern of indicia thereon, and an image of the pattern of indicia when the template is positioned on the slap print prism shown in FIG. **16**.

FIG. **37** is a graphic representation of a curvature corrected array generated by the processor subsystem shown in FIG. **20** and representative of the image of the pattern of indicia shown in FIG. **36**.

FIG. **38** is a graphic representation of a table of vertical scale correction data generated by the processor subsystem from the curvature corrected array shown in FIG. **37**, and used to generate a vertically scaled array.

FIG. **39** is a graphic representation of a horizontally scaled array of horizontally scaled pixel values generated by the processor subsystem shown in FIG. **20**.

FIG. **40** is a graphic representation of a table of horizontal scale correction data generated by processor subsystem from the image of the pattern of indicia shown in FIG. **32** and used to produce the vertically scaled array shown in FIG. **39**.

FIG. **41** is a graphic representation of a vertically scaled array representative of the image of the pattern of indicia shown in FIG. **32**.

FIG. **42** is an illustration of a Main Display menu generated and displayed by the data terminal shown in FIG. **1**.

FIG. **43** is a detailed view of the display on the optics/processor unit shown in FIG. **1**.

FIG. **44** is a detailed view of the key pad on the optics/processor unit shown in FIG. **1**.

FIG. **45** is an illustration of a Demographic/Department Information menu generated and displayed by the data terminal shown in FIG. **1**.

FIG. **46** is an illustration of a Processing Choices menu generated and displayed by the data terminal shown in FIG. **1**.

FIG. **47** is a graphic representation of a booking or applicant card onto which fingerprint images, department information and demographic information can be printed by the printer shown in FIG. **1**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Overall System and Optics Subsystem Description

An optical fingerprinting system **10** in accordance with the present invention is illustrated generally in FIG. **1**. As shown, fingerprinting system **10** includes an optics/processor unit **12**, video monitor **14**, printer **16**, and data terminal **6**, which includes a keyboard **7** and monitor **8**. Data terminal **6**, monitor **14** and printer **16** are interfaced to optics/processor unit **12**. Fingerprinting system **10** is capable of providing printed records of both plain or "slap" prints which are simultaneous impressions of the fingerprints of all fingers of a hand other than the thumb, and individual fingerprints.

To take a slap print, the person to be fingerprinted will position the fingertips of their index, middle, ring and little fingers on slap print prism **18'**. Optics/processor unit **12** images the slap print and provides a real-time visual display thereof on monitor **14**. When an operator observes a satisfactory slap print image on monitor **14**, a key **17A–17D** on key pad **19** is actuated causing optics/processor unit **12** to "freeze" the image by storing digital data representative thereof. This image is then enhanced when the digital data is processed by optics/processor unit **12** in accordance with image enhancement software. Data representative of the enhanced image is then stored. If it is desired to fingerprint an individual finger, the person to be fingerprinted will position their finger within groove **102** of an individual finger prism such as **20A**. Optics/processor unit **12** will image the fingerprint, and provide a display thereof on monitor **14**. This image can then be "frozen", and data representative thereof processed by optics/processor unit **12** and stored.

Demographic data characteristic of the person being fingerprinted and department data (or other relevant information) utilized by the organization doing the fingerprinting can be entered into system **10** by the operator through keyboard **7**. This data, along with the stored fingerprint images, can then be printed at proper locations on a document such as a standard booking or applicant card **15** by printer **16**. These procedures are all facilitated by system generated menus and prompts which are displayed on monitor **8** of data terminal **6**, as well as by display **13** and illumination of buttons **17A–17D** of key pad **19**.

An optics subsystem **22** within optics/processor unit **12** is illustrated in greater detail in FIGS. **2**, **3A** and **3B**. Optics subsystem **22** includes slap print prism **18'**, finger prism trolley **24**, first slap image mirror **25**, slap/finger image selection optics **26**, and a sensor such as video camera **28**. Slap print prism **18'** is mounted in such a manner that its finger-receiving surface **150** is generally level and coplanar with a stepped top panel **32** of unit **12**. First slap image mirror **25** is mounted with respect to slap print prism **18'** so as to receive slap fingerprint images projected from image projection surface **156** of the prism, and to reflect these images to slap/finger image selection optics **26**. Slap print prism **18'** is illuminated by means of a light source such as lamp **31** which is positioned adjacent to a light-receiving surface **162** of the prism. In the embodiment shown, lamp **31** is a sideways oriented U-shaped fluorescent bulb having two legs which are shown in cross section. The two legs of lamp **31** extend across light-receiving surface **162** of prism **18'**, and are surrounded on a side opposite prism **18'** by reflector **32**.

Finger prism trolley **24**, which is illustrated in greater detail in FIG. **4**, includes a base **34** to which a plurality of individual finger prisms **20A–20D** are mounted by screws or other suitable fasteners (not shown). Base **34** includes a track-follower section **36** which is slidably received upon a guide track **37**. Guide track **37**, in turn, is mounted with respect to a sloping front panel **38** of unit **12** by means of a mounting bracket **39**. As shown in FIGS. **2** and **4**, each finger prism **20A–20D** has an upper surface **100** which includes a finger-receiving groove **102**. Prisms **20A–20D** are spaced from one another by triangular shaped mirror blocks **40** which have reflective or mirror side surfaces **41** which angle away from side surfaces **112** of prisms **20A–20D** and intersect at a point toward slap/finger image selection optics **26**. End mirror blocks **42** are positioned adjacent side surfaces **112** of prisms **20A** and **20D** which are opposite mirror blocks **40**. End mirror blocks **42** also have a reflective side surface **43** which angles away from side surfaces **112** in a direction toward slap/finger selection optics **26**. Mirror blocks **40** have their top surface covered by cover plates **44** (some of which are shown in phantom in FIG. **2**) which extend between adjacent prisms **20A–20D**.

Finger prism trolley **24** is mounted with respect to unit **12** at an angle in such a manner that finger-receiving grooves **102** of prisms **20A–20D** are generally parallel with top panel **50** of the unit. As perhaps best shown in FIGS. **1, 3A** and **3B**, a finger-receiving cutout or aperture **51** extends through top panel **50** and sloping side panel **38** at a position adjacent trolley **24** to expose groove **102** of one of prisms **20A–20D**. By means of trolley handle **52** which extends through panel **38**, an operator can slide trolley **24** along guide track **37** in such a manner as to position groove **102** of a desired finger prism **20A–20D** adjacent aperture **51**. A lamp **53**, which can be identical to lamp **31** previously described, is mounted with respect to unit **12** below aperture **51** and adjacent a light-receiving surface **104** of whichever prism **20A–20D** has been positioned adjacent aperture **51**. Light from lamp **53** will directly enter light-receiving surface **104**, and be reflected by surfaces **41** and **43** of mirror blocks **40** and **42**, respectively, into side walls **112** of the selected finger prism **20A–20D**. A fingerprint image of a finger positione- within groove **102** of the selected prism **20A–20D** will thereby be propagated from image propagation surface **106** toward slap/finger image selection optics **26**.

Slap/finger image selection optics **26** includes a mounting plate **60** which has a second slap image mirror **61** and a slap image focusing lens assembly **62**, as well as a finger image mirror **63** and finger image focusing lens assembly **64** mounted to a lower side thereof. Finger image mirror **63** is mounted to mounting plate **60** by means of mounting brackets **65**, and is oriented at an angle so as to receive fingerprint images propagated from one of finger prisms **20A–20D** and to reflect the fingerprint image to a lens (not separately visible) within finger image focus lens assembly **64**. Lens assembly **64** is mounted to mounting plate **60** by means of mounting bracket **66**. Second slap image mirror **61** is mounted to mounting plate **60** by mounting brackets **67** at a position adjacent finger image mirror **63**. Mirror **61** is oriented at such an angle as to receive slap print images from first slap image mirror **25**, and to reflect these images to a lens (not separately visible) within lens assembly **62**. Lens assembly **62** is mounted to mounting plate **60** by means of mounting bracket **68**. The lenses within lens assemblies **62** and **64** can be adjustably positioned along their optical axis to facilitate optical focusing adjustments of subsystem **22**.

As shown in FIG. **2**, a motor mounting bracket **70** is mounted to a left side panel **71L** of unit **12**, while a support bracket **72** is mounted to right side panel **71R**. Mounted to and extending bbetween brackets **70** and **72** is a pair of guide rods **73**. Guide rods **73** are mounted to brackets **70** and **72** by means of fasteners **74** in the embodiment shown. Mounting plate **60** is slidably suspended from guide rods **73** by means of slide bushings **75A–75C**.

A motor **76** which is interfaced to processor subsystem **30** is mounted to a lower face (not visible) of mounting bracket **70**, and has a drive shaft **77** which extends through the bracket. A drive wheel **78** is mounted to shaft **77**. An idler wheel **79** is rotatably mounted to an idler bracket **99**. Idler bracket **99** is mounted acrossguide rods **73**.

Looped between drive wheel **78** and idler wheel **79** is a drive belt **80**.

A flexible fastening assembly **81** for flexibly fastening belt **80** to mounting plate **60** is illustrated in FIG. **5**. Fastening assembly **81** includes a clamp **82** which has a slot (FIG. **2**) into which drive belt **80** is fixedly clamped. Clamp **82** also has a pair of downward extending arms **83** on its opposite sides. Ends of a flexible member such as stretched spring **84** are fastened to arms **83**. A central portion of spring **84** is fastened to mounting plate **60** by means of clamp or bracket **85**.

Motor **76** is interfaced to a processor subsystem **30** of optics/processor unit **12**. In response to finger prism select signals from processor subsystem **30**, motor **76** will rotate in a clockwise direction as viewed in FIG. **2**, thereby driving mounting plate **60** (slap/finger image selection optics **26**) along guide rods **73** to a rightmost or finger prism select position illustrated in FIGS. **2** and **3A**. Mounting plate **60** is driven in this manner until slide bushing **75B** is positioned against adjustable stop **86** and actuates microswitch **87**. Microswitch **87** is interfaced to processor subsystem **30**, and provides signals representative of the positioning of mounting plate **60** to the finger prism select positon.

With slap/finger image selection optics **26** in the finger prism select position, video camera **28**, finger prism focus lens assembly **64**, and finger image mirror **63** are all aligned with the finger prism **20A–20D** with has been positioned adjacent aperture **51**. Visual images of fingerprints of fingers positioned with groove **102** will thereby be propagated from image propagation surface **106** of the selected prism **20A–20D** along finger image optical path **88**, reflecte by mirror **63**, focused by the lens within assembly **64**, and imaged by camera **28**.

In response to slap print prism select signals from processor subsystem **30**, motor **76** will rotate in a counterclockwise direction, thereby pulling mounting plate **60** and slap/finger image selection optics **26** to a slap print select or leftmost position (not shown) when viewed from FIG. **2**. Slide bushing **75C** will then actuate microswitch **89**, which in turn provides slap print positioning select signals to processor subsystem **30**. Processor subsystem **30** then stops rotation of motor **76**.

As illustrated in FIG. 3B, when selection optics 26 are properly positioned in the slap print select position, second slap image mirror 61 and slap print focusing lens assembly 62 will be aligned about a slap print optical path 90 between slap print prism 18', first slap image mirror 25, and camera 28. Slap print images of fingers positioned on slap print prism 18' will thereby be propagated from image propagation surface 156 of the prism along slap print optical path 90, reflected by mirrors 25 and 61, focused by the lens within assembly 62, and imaged by camera 28. Video signals representative of fingerprint images imaged by camera 28 are provided to processor subsystem 30. Key pad 19 is illustrated in FIGS. 1, 20, and 44. As perhaps best illustrated in FIG. 44, key pad 19 is formed by a YES key 17A, a NO key 17B, a CAPTURE key 17C, and an amputee or AMP Key 17D. Keys 17A–17D are preferably fabricated of a translucent material such as plastic, and have a light source such as LEDs 21A–21D, respectively, positioned thereunder. LEDs 21A–21D are each individually interfaced to processor subsystem 30 as shown, and can be individually lit or illuminated by the processor subsystem.

Display 13 is illustrated in greater detail in FIG. 43. As shown, display 13 includes a left hand representation or indicia 312, and a right hand indicia 314. Each finger of indicia 312 and 314 have a light such as LEDs 316A≅316E and 318A–318E associated therewith. In the embodiment illustrated in FIG. 43, LEDs 316A–316E are positioned in the thumb, index, middle, ring, and little fingers of left hand indicia 312. Leds 318A–318E are positioned in the thumb, index, middle, ring and little fingers of right hand indicia 314. Leds 316A–316E and 318A–318E are each interfaced (FIG. 20) individually to processor subsystem 30 so as to be capable of individual illumination thereby.

Individual Finger Prisms

Individual finger prism 20A, which is representative of individual finger prisms 20A–20D, is perhaps best described with reference to FIGS. 6–11. Prism 20A is an optical device fabricated of light-propagating material such as plastic which is characterized by an index of refraction. In one embodiment, prisms 20A–20D are machined from acrylic polymer, although they can also be molded from this or other materials.

As shown, prism 20A has a first or sloping upper surface 100 which has a finger-receiving groove 102 therein, and a front face which includes both a second or light-receiving surface 104 and a third or image propagation surface 106. Prism 20A also includes a fourth or bottom surface 108, a fifth or back surface 110, and two side faces or surfaces 112.

Prism 20A has a width of dimension D1, and an overall depth of dimension D2. Back surface 110 is perpendicular to bottom surface 108 and extends to a height of dimension D3 from the bottom surface. Upper surface 100 intersects back surface 110 at an angle Al with respect to bottom surface 108. Light-receiving surface 104 extends perpendicularly from bottom surface 108 to a height of dimension D4. The magnitude of angle A1 will depend upon the index of refraction of the material from which prism 20A is manufactured. In one preferred embodiment in which prism 20A is manufactured of acrylic polymer, angle A1 is 35°. In this same embodiment, dimensions D1–D4 are 1.58 inches, 2.35 inches, 1.62 inches, and 0.95 inches, respectively.

As shown in FIGS. 6, 7, 8, and 10, groove 102 is elongated and contoured to receive a finger. Groove 102 includes both a fingerbody portion 113 and a fingertip portion 114. Fingerbody portion 113 and fingertip portion 114 of groove 102 both include a bottom wall 116 and side walls 118. As best shown in FIG. 7, the deepest part of bottom wall 116 of fingerbody portion 113 is at a constant depth of dimension D8 with respect to upper surface 100. The deepest part of bottom wall 116 of fingertip portion 114 slopes from its intersection with fingerbody portion 113 toward upper surface 100 at an angle A5 (45° in one embodiment) with respect to bottom surface 108. In the embodiment shown in FIG. 7, bottom wall 116 curves between portions 113 and 114 at a radius of curvature defined by dimension D6. In one preferred embodiment, dimension D6 is a 2.00 inch radius of curvature. This radius of curvature (dimension D6) is centered at a point displaced from the intersection of upper surface 100 and back surface 110 by length of dimension D7. Following the embodiment described above, dimension D8 is 0.50 inches while dimension D7 is 0.72 inches.

As perhaps best shown in FIG. 5, bottom wall 116 of groove 102 is semicircular having a radius of curvature characterized by dimension D8. This radius of curvature (dimension D8) can be constant throughout the length of groove 102. Side walls 118 are preferably planar, and form an angle A2 with respect to side surfaces 112 which are perpendicular to both upper surface 100 and bottom surface 108 of prism 20A. In one preferred embodiment, angle A2 is 22½°.

The above-described characteristics of groove 102 have been found to permit the highest or optimum degree of contact between a finger (not shown in FIGS. 6–11) and the various surfaces of the groove. This feature is especially important for fingertip portion 114 of groove 102 so that an image of the largest possible area of the fingerprint on the tip of a finger is propagated from prism 20A. Dimensions D6, D7 and D8, as well as angle A2, will of course vary depending upon the size of the finger to be received by groove 102. As shown in FIGS. 2 and 4, the size of grooves 102 of each prism 20A–20D on trolley 24 is different so that a prism having a properly sized groove 102 can be selected as needed for the particular finger of a particular person being fingerprinted. In general, the larger the finger being fingerprinted, the larger the groove 102 of the selected prism 20A–20D. Dimension D1 of prism 20A will of course also have to increase for prisms 20A–20D with larger grooves 102 (dimension D8).

In the embodiment of prism 20A shown in FIGS. 6–11, image propagation surface 106 and light-receiving surface 104 are both curved so as to function as lenses. Light-receiving surface 104 forms a cylindrical lens and has a radius of curvature defined by dimension D9. This radius of curvature (dimension D9) is centered about a point of dimension D½ from side surfaces 112, and spaced from back surface 110 by a distance of dimension D10. In the embodiment of prism 20A described above, dimension D9 is 1.88 inches while dimension D10 is 0.25 inches. The radius of curvature or dimension D9 of lensed light-receiving surface 104 is therefore perpendicular to back surface 110 and parallel to bottom surface 108. Alternatively, light-receiving surface 104 can be characterized as being cylindrically curved about an imaginary vertical axis 105 which is perpendicular to bottom surface 108 and parallel to back surface 110.

Image propagation surface **106** is formed as a spherical convex lens in the embodiment shown, and has a radius of curvature of dimension D11 in both horizontal (X) and vertical (Y) directions. In the embodiment of prism **20A** illustrated in FIGS. **6–11**, radius of curvature or dimension D11 is centered at a distance of dimension D3 from bottom surface **108**, halfway about back surface **110** ($d\frac{1}{2}$) and a distance of dimension D10 from back surface **110**. In the embodiment described above, dimension D11 is 2.00 inches.

To increase the contrast of fingerprint images provided by or propagated from prism **20A**, various surfaces are coated by an opaque substance to inhibit transmission of light. In the embodiment shown, bottom surface **108**, back surface **110**, and planar portions of upper surface **100** other than those of groove **102** are coated with an opaque substance. In addition, portions of side surfaces **112** adjacent back surface **110** (those portions at which mirror blocks **40** or **42** meet prisms **20A–20D** as shown in FIG. **2**) are also coated. Black paint can be applied to the above-identified surfaces to prevent transmission of light through absorption.

The optical properties of prism **20A** (which are similar to those of prisms **20A–20D**) are described with reference to FIGS. **12–14**. Prism **20A** is designed to utilize the optical principal of frustration of total internal reflection. Due to the relative indexes of refraction of air and the material of which the prism **20A** is constructed, and the angles of upper surface **100** and surfaces **116** and **118** of groove **102** with respect to image propagation surface **106** and light-receiving surface **104**, all light incident upon groove **102** when a finger is not present thereon is refracted downward toward bottom surface **108** or sideways toward side surfaces **112** upon its entry into prism **20A** as illustrated in FIG. **12**. Most importantly, virtually none of the light entering groove **102** will be directed out of image propagation surface **106**. Virtually all of the light which strikes bottom surface **108** or the opaque portions of side surfaces **112** is absorbed due to the opaque coating, and not re-reflected.

Light from lamp **53** will enter prism **20A** through light receiving surface **104**, image propagation surface **106**, and portions of side faces **112** which are not coated with opaque material. Light so entering which impinges upon groove **102** will either pass through the groove and exit prism **20A**, or be internally reflected to one of the opaque surfaces such as bottom surface **108** or back surface **110**, and absorbed. Virtually none of the light incident upon prism **20A** from lamp **53** will exit image propagation surface **106**. As a result, an observer looking into image propagation surface **106** will see only "black" when no finger is positioned on surfaces **116** or **118** of groove **102**.

Characteristics of a finger **132** are described with reference to FIG. **15** for use throughout subsequent portions of this specification. As shown, the tip of finger **132** has a finger pad or base area which has a fingerprint **134** thereon. Fingerprint **134** is a pattern formed by ridges **136** (light areas) and valleys **138** (dark areas) of the finger pad.

Referring back to FIGS. **13** and **14**, when finger **132** is positioned within groove **102**, the total internal reflection properties of prism **20A** are frustrated or destroyed at points at which ridges **136** of the fingerpad contact surfaces **116** and **118** of groove **102**. As shown in detail in FIG. **14**, portions of prism **20A** at which ridges **136** contact a surface such as **116** of groove **102** are characterized by a skin-prism material boundary, while those portions at which valleys **138** are adjacent surface **116** are characterized by an air-prism material boundary as if a finger were never positioned in groove **102**. At the areas at which ridges **136** contact surfaces **116** or **118** of groove **102**, light which passes through the groove and into the skin will be partially absorbed by the skin and partially re-reflected back into prism **20A**. Due to the different index of refraction of skin from that of air, this light which re-enters prism **20A** at a skin-prism material boundary is refracted toward image propagation surface **106** and propagated therethrough. However, light which re-enters groove **102** at areas at which valleys **138** are adjacent surfaces **116** and **118** behaves as previously described due to the air-prism material interface between groove **102** and finger **132**. When this light re-enters prism **20A**, it is refracted downard and absorbed as previously described. These properties are illustrated graphically in FIG. **13**. As a result, a visual image of fingerprint **134** (fingerprint image) is propagated through image propagation surface **106**. This fingerprint image has "light" areas corresponding to ridges **136** of the fingerprint **134**, and "dark" areas corresponding to valleys **138**.

The fingerprint image of finger **132** propagated from prism **20A** will be distorted from that of a planar "rolled" fingerprint image of the same finger. These distortions are broadly characterized as curvature errors, and size or scale errors, and are caused by different characteristics of finger **132**, prism **20A**, and their interaction.

As illustrated in FIG. **15**, fingers such as **132** can be characterized by an imaginary longitudinal axis **139** which extends along the finger. The fingerpad on which fingerprint **134** is located is a compound curved surface in that it has base curvature about both an X-base curve axis **140** (generally referred to as an X-axis) and a Y-base curve axis **141** (generally referred to as a Y-axis). X-base curve axis **140** is oriented in a circumferential direction about longitudinal axis **139**, and is formed by a locus of points which are perpendicular to a given point about the longitudinal axis.

Portions of fingerprint **134** about an X-base curve axis such as **140** would be colinear in a rolled fingerprint of fingerprint **134**. However, the fingerprint image of fingerprint **134** propagated from image propagation surface **106** of prism **20A** is planar, with an imaginary axis **142** which is perpendicular to the image plane (i.e., a plane "parallel" to image propagation surface **106**) forming an observation angle OA with respect to longitudinal axis **139** of finger **132**. Observation angle OA will be equal to angle **A1** (FIG. **7**) for those portions of the fingerprint image corresponding to portions of finger **132** which are positioned on fingerbody portion **113** of groove **102**. Observation angle OA increases in accordance with the upwardly curved bottom wall **116** for those portions of the fingerprint image corresponding to portions of finger **132** which are positioned on fingertip portion **114** of groove **102**. As a result of finger **132** being imaged at an observation angle OA which is between zero and ninety degrees and the curved nature of fingerprint **134** about X-base curve axis **140**, portions of fingerprint **134** along an X-base curve axis such as **140** will appear as being curved upward in the fingerprint image, as opposed to being colinear if imaged at an observation angle OA of ninety degrees.

A graphic representation of these curvature errors inherently produced by prism **20A** is illustrated in FIG.

32 where an image of a line **254** is curved about an X-base curve axis such as **140** and positioned in groove **102**. Although in theory the amount of curvature error changes for portions of fingerprint **134** at different X-base curve axes such as **140** along Y-base curve axis **141**, in practice the amount of curvature error variation over the relatively small part of finger **132** which is imaged is small. Curvature errors at all points of fingerprint **134** along Y-axis **141** are therefore essentially equal.

Scale errors are also caused by the fact that fingerprint **134** is on a compound curved surface of finger **132**, and is imaged at an observation angle OA other than ninety degrees with respect to longitudinal axis **139**. As a result of being imaged at an observation angle OA, true distances of portions of fingerprint **134** along a given Y-base curve axis such as **141** will be distorted. For example, in the fingerprint image, two ridges **136** which are actually separated about Y-base curve axis **141** on the finger by a given amount will appear to be compressed and separated by a distance less than the given amount. Furthermore, this Y-axis scale error is not constant about Y-base curve axis **141** since observation angle OA increases as bottom surface **116** in fingertip portion **114** of groove **102** curves upward toward surface **100** in the direction of image propagation surface **106**.

For similar reasons, X-axis scale errors are inherent in portions of the fingerprint image which represent portions of the fingerprint about an X-base curve axis such as **140**. These X-axis scale errors are also nonlinear due to curvature of fingerprint **134** along its X-base curve axis **140**. For example, portions of fingerprint **134** at its center (i.e., opposite the fingernail), and portions on its side, which are separated by a given distance along X-base curve axis **140** will appear to be separated by different distances in the fingerprint image. Distances on the side of finger **132** will be compressed with respect to those in the center of the fingerprint.

The curved or lensed nature of image propagation surface **106** of prism **20A** magnifies the fingerprint image of fingerprint **134** before it is propagated therefrom. Since groove **102** is actually an elongated and compound curved surface, different portions of the groove, and therefore different portions of fingerprint **134** when finger **132** is placed within the groove, will be at different distances from image propagation surface **106**. This factor coupled with well known geometric optic principles results in different portions of fingerprint **134** being magnified to different degrees or amounts. Portions of fingerprint **134** near tip **145** of finger **132** will be nearest surface **106** and magnified the least amount. Portions of fingerprint **134** near back **143** of finger **132** will be positioned furthest from surface **106** and magnified the most. Portions of fingerprint **134** near sides **144** (only one side is visible in FIG. **15**) will be magnified by an amount between the amount of those portions at back **143** and tip **145**.

The result of these different amounts of magnification is to partially correct for curvature and scale errors described above. Curvature and scale errors in the fingerprint image which correspond to portions of fingerprint **134** at sides **144** of finger **132** are reduced due to the magnification (i.e., the inherent compression is expanded). Scale errors in the fingerprint image which correspond to portions of fingerprint **134** at back **143** of finger **132** are also reduced for similar reasons. In general, the magnification properties of image propagation surface **106** of prism **20A** have been found to reduce the curvature and scale erros in the fingerprint image.

Slap Print Prism

A first embodiment of slap print prism **18** is illustrated in FIGS. **16** and **17**. Like individual finger prism **20A**, slap print prism **18** has a first or finger-receiving surface **150**, a second or light-receiving surface **154**, a third or image propagation surface **156**, a fourth or bottom surface **158**, back surface **160**, and side surfaces **162**. Bottom surface **158** has a depth of dimension **D20**, and a width of dimension **D21**. Light-receiving surface **154** and back surface **160** are perpendicular to and have a height of dimensions **D22** and **D23**, respectively, from bottom surface **158**. Finger receiving surface **150** is planar, and forms an angle **A5** with respect to bottom surface **158**. Image propagation surface **156** is curved to function as a cylindrical lens, and has a radius of curvature of dimension **D24** centered about a point at a distance of dimension **D25** above the intersection of finger-receiving surface **150** and back surface **160**, and a distance of dimension **D26** toward light-receiving surface **154** from back surface **160**. Image propagation surface **156** can therefore be characterized as a cylindrical lens having a radius of curvature about an imaginary horizontal axis **151** which is parallel to both back surface **160** and bottom surface **158**. Dimension **D21** of slap print prism **18** must be sufficient so as to enable a plurality of fingers (e.g., four fingers of a hand less the thumb) to be positioned on finger-receiving surface **150**. In one preferred embodiment, dimension **D21** is five inches. In the same embodiment, dimension **D20** is 1.75 inches, dimension **D22** is 1.38 inches, dimension **D23** is 1.25 inches, dimension **D24** is 1.00 inches, dimension **D25** is 0.75, and dimension **D26** is 0.88 inches.

Slap print rism **18** utilizes and operates on the same optical principles as that of individual fingerprint prism **20A** described above. Bottom surface **158**, side surfaces **162**, and back surface **160** are coated with black paint so as to make these surfaces opaque. Slap print images of the four fingers of a hand, excluding the thumb, which are positioned on finger-receiving surface **150** will be propagated through image propagation surface **156**. Valleys **138** of a finger such as **132** (FIG. **15**) will be "dark" in the image, while ridges **136** will be light. The curved nature of image propagation surface **156** causes this surface to function as a lens, and magnifies the image in a direction corresponding to that along the longitudinal axis (i.e., Y-base curve axis) of the finger. This magnification partially corrects for scale errors along Y-base curve axis **141** (FIG. **15**) due to the observation angle OA at which fingerprint **134** is imaged. Since finger-receiving surface **150** is planar, fingerprint **134** of a finger such as **132** is forced into a planar orientation when positioned on surface **150**. As a result, X-axis curvature and scale errors in fingerprint images provided by slap print lens **18** are negligible compared to those of images provided by finger prisms such as **20A**.

A second or alternative embodiment of the slap print prism, that being slap print prism **18'**, is illustrated in FIGS. **3A**, **3B**, **18** and **19**. Slap print lens **18'** is identical to slap print lens **18** previously described in all respects except for image propagation surface **156'** which is coplanar with light-receiving surface **162**. Image propagation surface **156'** does not, therefore, magnify fingerprint images of fingers such as **132** positioned on finger-receiving surface **150**. As a result, Y-axis scaling errors are not partially corrected. Slap print lens **18'** functions in all other regards exactly like that of slap print lens **18** previously described.

Processor Subsystem

Processor subsystem **30** and its interrelationship to video camera **28**, video monitor **14**, printer **16**, data terminal **6**, LEDs **316A–316E** and **318A–318E** of display **13**, LEDs **21A–21D** of key pad **19**, motor **76** and microswitches **87** and **89** is best described with reference to FIG. **20**. As shown, processor subsystem **30** includes programmable computing means such as computer **200**, random access memory or RAM **202**, read only memory or ROM **204**, and frame digitizer **206**.

Fingerprint images from optics subsystem **22** are imaged by camera **28** through its objective lens. In response, camera **28** generates video signals which are representative of the fingerprint image. The video signals are then distributed to both video monitor **14** and frame digitizer **206**. Video monitor **14** (which will typically be interfaced to microprocessor **200** through a video driver which is not shown) can thereby provide a real-time display of the fingerprint image being imaged by camera **28**. In one preferred embodiment, camera **28** and monitor **14** are commercially available devices which utilize a standard raster and standard frame rates. Computer **200** is preferably a commercially available 32-bit microprocessor.

When an operator of fingerprinting system **10** observes on monitor **14** a fingerprint image they wish to "freeze" or record, key pad **19** will be appropriately actuated. In response, computer **200** will cause frame digitizer **206** to digitize the video signals of the frame being displayed on monitor **14**, and provide digital image data characteristic of the "captured" fingerprint image to computer **200**. The fingerprint image data is temporarily stored in RAM **202**. Computer **200** then retrieves the fingerprint image data and processes it in accordance with image enhancement software programs which can be stored in ROM **204**. Computer **200** thereby generates enhanced fingerprint image data. In response to operator control through data terminal **6**, computer **200** can retrieve the enhanced image data from RAM **202** and provide it to video monitor **14**. The enhanced fingerprint image can thereby be visually displayed. Alternatively, the operator can cause the enhanced image data to be propagated to printer **16** which will print the enhanced fingerprint image. Printer **16** is preferably a high resolution laser printer.

Frame digitizer **206** provides the digital image data in the form of an array of pixel values representative of the intensity of the fingerprint image at corresponding discrete or pixel locations. An image array IA of pixel values PVn,m_I is illustrated in FIG. **21**. Image array IA is formed of N rows and M columns of pixel values PVn,m_I. In one embodiment, image array IA is formed of N equal to four hundred and eighty rows and M equal to five hundred and twelve columns of pixel values PVn,m_I. Pixel values PVn,m_I are digital values representative of the intensity of the fingerprint image at corresponding pixel locations PLn,m of image array IA. In one embodiment frame digitizer **206** includes an eight-bit analog-to-digital converter which converts the video signals to eight-bit pixel values PVn,m_I characteristic of image intensity at corresponding pixel locations PLn,m. In this embodiment, an eight-bit pixel value PVn,m_I representative of a decimal zero (i.e. "00000000") is a minimum pixel value PVMIN and characterizes a lowest intensity or darkest pixel location PLn,m. A pixel value representative of a decimal two hundred and fifty-six (i.e., "11111111") is a maximum pixel value PVMAX and represents a highest intensity or whitest pixel location. A pixel value PVn,m_I representative of a digital **128** (i.e., "10101010") represents a pixel location PLn,m having an intensity half-way between the lowest and highest intensities(i.e., grey).

Having been generated by frame digitizer **206**, pixel values PVn,m_I of image array IA will be stored within RAM **202** at indexed locations corresponding to pixel locations PLn,m. Computer **200** will then retrieve image array pixel values PVn,m_I and process them in accordance with a Noise Average software algorithm stored in ROM **204** to produce a noise averaged array NAA of pixel values PVn,m_N(FIG. **22**. Noise averaged pixel values PVn,m_N are then temporarily stored within RAM **202** prior to implementation of subsequent image processing software algorithms. Following this approach, computer **200** generates an illumination equalized array IEA of illumination equalized pixel values PVn,m_E in accordance with an Illumination Equalize algorithm, a directional filtered array DFA of directional filtered pixel values PVn,m_D in accordance with a Directional Filter algorithm, and an unhaired array UA of unhaired (artifact removed) pixel values PVn,m_U in accordance with an Unhair algorithm. Unhaired pixel values PVn,m_U are then translated in position in accordance with a Curvature Correction algorithm to generate a curvature corrected array CCA of curvature corrected pixel values PVn,m_C. Curvature corrected pixel values PVn,m_C are then scaled or translated in position, first vertically to produce a vertically scaled array VA of vertically scaled pixel values PVn,m_V, and then horizontally to produce a horizontally scaled array HA of horizontally scaled pixel values PVn,m_H. This processing is done in accordance with Vertical Scaling and Horizontal Scaling algorithms, respectively. Finally, the horizontally scaled array HA of pixel values PVn,m_H is thresholded to produce a threshold array of thresholded values PVn,m_T characteristic of the enhanced fingerprint image. The thresholded array of pixel values are then stored in RAM **202**, and can be utilized by printer **16** to produce a printed record of the fingerprint image.

A. Noise Average

To initiate image processing, computer **200** will retrieve pixel values PVn,m_I of image array IA (FIG. **21**) from RAM **202**, and process these pixel values in accordance with a Noise Average program stored within ROM **204**. As a result of this processing, computer **200** generates a noise averaged array NAA of noise averaged pixel values PVn,m_N as illustrated in FIG. **22**. The Noise Average program removes random variations, or noise, in imaged pixel values PVn,m_I which can be introduced for various reasons such as electronic or electromagnetic noise.

Each noise averaged pixel value PVn,m_N at pixel locations PLn,m of noise averaged array NAA is computed as a function of weighted average of the particular image pixel value PVn,m_I at the same pixel location PLn,m of image array IA, and a plurality of image pixel values PVn,m_I at pixel locations PLn,m surrounding or in the area of the particular pixel value PVn,m_I being noise averaged. In a preferred embodiment described below, noise averaged pixel values PVn,m_N are computed as a function of a weighted average of a given image pixel value PVn,m_I, and pixel values PVn,m_I at pixel locations PLn,m of image array IA immediately adjacent to the given pixel value. A formula for computing noise averaged pixel values PVn,m_N in accordance with a preferred weighted average function is described by Equation 1 below. Other weighted average functions can of course also be used.

$$PVn,m_N = [4PVn,m_I + 2(PVn-1,m_I + PVn,m+1_I + PVn+1,m_I + PVn,m-1_I) + PVn-1,m-1_I + PVn-1,m+1_I + PVn+1,m+1_I + PVn+1,m-1_I]/16 \quad \text{Eq. 1}$$

The weighted average function of Equation 1 assigns the center pixel value PVn,m_I (the particular pixel value to be noise averaged) a weight of four, adjacent side pixel values a weight of two, and adjacent corner pixel values a weight of one. Equation 2 below describes as an example the application of Equation 1 to a particular image pixel value $PV2,2_I$ to be noise averaged.

$$PV2,2_N = [4PV2,2_I + 2(PV1,2_I + PV2,3_I + PV3,2_I + PV2,1_I) + PV1,1_I + PV1,3_I + PV3,3_I + PV3,1_I]/16. \quad \text{Eq. 2}$$

It is evident that the weighted average function described by Equation 1 is not applicable to pixel values PVn,m_I at pixel locations PLn,m at the edge of image array IA (i.e., pixel values PVn,m_I for $n=1$ and $1 \leqq m \leqq M$, for $1 \leqq n \leqq N$ and $m=1$, for $n=N$ and $1 \leqq m \leqq M$, for $1 \leqq n \leqq N$ and $m=M$). The reason is that there are no "adjacent" pixel values beyond the edge of image array IA. In one embodiment these "edge" pixel values are ignored by the Noise Average program since they likely represent unimportant portions of the fingerprint image anyway. The noise averaged pixel values PVn,m_N at these edges are simply set equal to their corresponding pixel values PVn,m_I in the image array, as described by Equation 3.

$$PVn,m_N = PVn,m_I \text{ for: } n=1, 1 \leqq m \leqq M; \quad 1 \leqq n \leqq N, m=1; \quad n=N, 1 \leqq m \leqq M; \text{ and } \quad 1 \leqq n \leqq N, m=M \quad \text{Eq. 3}$$

Having generated a noise averaged array NA of pixel values PVn,m_N in accordance with the above-described approach, computer **200** will store the noise averaged pixel values at indexed locations within RAM **202** for subsequent processing.

B. Illumination Equalize

In practice, the manner in which slap print prism **18'** and finger prisms **20A≅20D** are illuminated by lamps **31** and **53**, respectively, results in varying amounts of light being propagated by the prisms to different portions of a fingerprint such as **134** (FIG. **15**) being imaged. As a result, the illumination intensity level over each fingerprint image imaged by camera **28** will vary. However, it is desirable that the fingerprint be illuminated with a constant intensity throughout. This is effectively performed by computer **200** which processes pixel values PVn,m_N of noise averaged array NAA in accordance with an illumination Equalize program stored in ROM **204**, and generates an illumination equalized array IEA of illumination equalized pixel values PVn,m_E illustrated in FIG. **23**.

The generation of illumination equalized pixel values PVn,m_E from noise averaged pixel values PVn,m_N is described with reference to FIG. **24**. For a particular pixel value PVn,m_N at a particular pixel location PLn,m that it is desired to illumination equalize, computer **200** first selects a subarray SA of pixel values which includes the pixel value to be illumination equalized. Although subarray SA has been chosen as a three-by-three subarray with the particular pixel value PVn,m_N to be equalized in the center thereof for purposes of example in FIG. **24**, subarrays of a larger size are preferred and can produce better results. In one embodiment, computer **200** selects an eight-by-eight subarray of pixel values surrounding the pixel value to be illumination equalized. However, the algorithm is fully described with the three-by-three subarray SA illustrated in FIG. **24**.

Having selected a subarray SAn,m, for the particular pixel value PVn,m_N to be equalized, computer **200** will sum all pixel values PVn,m_N within the subarray, and divide by the number of pixel values summed, to generate a subarray average value SAVn,m. Equation 4 below mathematically describes this procedure for the general three-by-three subarray SAn,m illustrated in FIG. **24**.

$$SAVn,m = [PVn-1,m-1_N + PVn-1,m_N + PVn-1,m+1_N + PVn,m-1_N + PVn,m_N + PVn,m+1_N + PVn+1,m-1_N + PVn+1,m_N + PVn+1,m+1_N]/9 \quad \text{Eq. 4}$$

Computer **200** then computes the illumination equalized pixel value PVn,m_E as a function of the particular noise averaged pixel value PVn,m_N to be illumination equalized, the subarray average value SAVn,m for the particular pixel value to be illumination equalized, and a constant K characteristic of an average illumination expected of pixel values of the image. Constant K (which can be stored in RAM **202** or ROM **204**) is a threshold value and can be set as a function of noise in the fingerprint image. In one embodiment, constant K is representative of a pixel value PVn,m having an intensity halfway between the lowest and highest intensities which can be displayed on monitor **14** (e.g., K=(PVMAX−PVMIN)/2). Following the above example which utilizes an eight-bit analog-to-digital converter in frame digitizer **206**, K would equal one hundred and twenty-eight.

In the course of carrying out these computations, computer **200** first generates a pixel difference value PDVn,m representative of the difference between the particular pixel value PVn,m_N to be illumination equalized, and the subarray average value SAVn,m of the subarray of which it is an element. This operation is mathematically described by Equation 5.

$$PDVn,m = PVn,m_N - SAVn,m. \quad \text{EQ. 5}$$

Constant K is then added to pixel difference values PVDn,m to generate an intermediate illumination equalized pixel value IEPVn,m as described by Equation 6 below.

$$IEPVn,m = PDVn,m + K. \quad \text{Eq. 6}$$

The illumination equalized pixel value PVn,m_E is finally computed as a function of its corresponding intermediate illumination equalized pixel value IEPVn,m. If the intermediate illumination equalized pixel value IEPVn,m is less than the minimum pixel value PVMIN or greater than the maximum pixel value PVMAX, the illumination equalized pixel value PVn,m_E is unconditionally set to PVMIN or PVMAX, respectively. The illumination equalized pixel value PVn,m_E is set to the intermediate illumination equalized pixel value IEPVn,m if IEPVn,m is greater than or equal to the minimum pixel value PVMIN, and less than or equal to the maximum pixel value PVMAX. These relationships are mathematically described by Equations 7-9 below.

$$PVn,m_E = PVMIN \text{ if } IEPVn,m < PVMIN. \quad \text{Eq. 7}$$

$$PVn,m_E = IEPVn,m \text{ if } PVMIN \leqq IEPVn,m \leqq PVMAX. \quad \text{Eq. 8}$$

$$PVn,m_E = PVMAX \text{ if } IEPVn,m > PVMAX. \quad \text{Eq. 9}$$

The procedures described above, including the selection of a subarray and the mathematical operations described by Equations 4-9, are carried out by computer 200 to generate an illumination equalized pixel value PVn,m_E for each noise averaged pixel value PVn,m_N to be illumination equalized. However, since subarrays SA are selected in such a manner that the pixel value PVn,m_N to be illumination equalized is at or near its center, it is evident that this procedure cannot be used to illumination equalize pixel values PVn,m_N near edges of noise averaged array NAA. For example, using the three-by-three subarray SA illustrated in FIG. 24, it will not be possible to illumination equalize the pixel values PVn,m_N of the outermost rows and columns of noise averaged array NAA. Since these edge pixel values PVn,m_N will likely represent unimportant parts of the fingerprint image, they are simply set equal to their noise averaged pixel values as described by Equation 10. A similar procedure is followed when using a subarray SA of larger size.

$$PVn,m_E = PVn,m_N \text{ for: } \begin{cases} n = 1, 1 \leqq m \leqq M; \\ 1 \leqq n \leqq N, m = 1; \\ n = N, 1 \leqq m \leqq M; \text{ and} \\ 1 \leqq n \leqq N, m = M. \end{cases} \quad \text{Eq. 10}$$

Following the above-described procedure, an entire illumination equalized array IEA of pixel values PVn,m_E can be generated by computer 200. Computer 200 will store illumination equalized pixel values PVn,m_E in RAM 202 for subsequent processing.

C. Directional Filter

The fingerprint image characterized by illumination equalized array IEA is formed by pixel values PVn,m_E which represent relatively light curves characteristic of fingerprint ridges 136 (FIG. 15), and pixel values which represent relatively dark curves characteristic of fingerprint valleys 138. To enhance the fingerprint image represented by illumination equalized array IEA, it has been found advantageous to filter pixel values PVn,m_E in such a way as to emphasize the directional aspects of portions of the array representing fingerprint ridges 136 and valleys 138. This directional filtering is performed by computer 200 in accordance with a Directional Filter program stored within ROM 204. The result is a directional filtered array DFA of directional filtered pixel values PVn,m_D as illustrated in FIG. 25.

Generally stated, the Directional Filtering program is implemented by computer 200 in a multiple-step manner. First, for each particular pixel value PVn,m_E for $1<n<N$, $1 \leqq m<M$ of illumination equalized array IEA (i.e., for all pixel values pVn,m_E other than those in the top and bottom rows and rightmost column) computer 200 computes an absolute value of the difference between that particular pixel value and a horizontally adjacent pixel value (HorizDif), a vertically adjacent pixel value (VertDif), an adjacent pixel value at a positive slope (PosDif) and an adjacent pixel value at a negative slope (NegDif). This procedure is described generally by Equations 11-14 below.

$$HorizDifn,m = |PV\ n,m_E - PVn,m+1_E| \quad \text{Eq. 11}$$

$$VertDifn,m = |PVn,m_E - PVn+1,m_E| \quad \text{Eq. 12}$$

$$PosDifn,m = |PVn,m_E - PVn-1,m+1_E| \quad \text{Eq. 13}$$

$$NegDifn,m = |PVn,m_E - PVn+1,\ m+1_E| \quad \text{Eq. 14}$$

Horizontal difference values HorizDifn,m, vertical difference values VertDifn,m, positive difference values PosDifn,m and negative difference values NegDifn,m for pixel values PVn,m_E for each $1<n<N$ and $1 \leqq m<M$ are stored at indexed locations within RAM 202.

As illustrated graphically in FIG. 26, computer 200 next divides illumination equalized array IEA into a plurality of regular subarrays 230A-230Y (illustrated with solid lines) and offset subarrays 232A-232JJ (illustrated with broken lines). Offset subarrays 232A-232JJ are offset both horizontally and vertically with respect to regular subarrays 230A-230Y in the embodiment shown. All pixel values PVn,m_E of illumination equalized array IEA will be located within both one of regular subarrays 230A-230Y and one of offset subarrays 232A-232JJ. Subarrays 230A-230Y and 232A-232JJ are sized so as to have more pixel values PVn,m_E on a side than an expected width of a fingerprint ridge 136 (FIG. 15) or valley 138 as represented by the pixel values of the subarray. In one embodiment, computer 200 causes subarrays 230A-230Y and 232A-232JJ to be rectangular with 32 pixel values PVn,m_E per side when processing an image from a finger prism such as 20A.

Computer 200 next determines a "dominant direction" of the portion of the fingerprint image represented by pixel values PVn,m_E of each regular subarray 230A-230Y and each offset subarray 232A-232JJ. This is done as a function of the difference values HorizDifn,m, VertDifn,m, PosDifn,m, and NegDifn,m computed for the pixel values PVn,m_E within that particular subarray 230A-230Y and 232A-232JJ. This is done by computing, for each subarray 230A-230Y and 232A-232JJ, a sum HDSum, VDSum, PDSum, and NDSum of the difference values HorizDifn,m, VertDifn,m, PosDifn,m, and NegDifn,m, respectively, which were previously computed for pixel values PVn,m_E within that subarray. This procedure is mathematically described by Equations 15-22.

$HDSum_{230xx} = \Sigma HorizDifn,m$ Eq. 15 (For all PVn,m_E of
$VDSum_{230xx} = \Sigma VertDifn,m$ Eq. 16 subarray 230xx for

-continued

$PDSum_{230xx} = \Sigma PosDifn,m$	Eq. 17	which difference values
$NDSum_{230xx} = \Sigma NegDifn,m$	Eq. 18	were computed)
$HDSum_{232xx} = \Sigma HorizDifn,m$	Eq. 19	(For all PVn,m_E of
$VDSum_{232xx} = \Sigma VertDifn,m$	Eq. 20	subarray 232xx for
$PDSum_{232xx} = \Sigma PosDifn,m$	Eq. 21	which difference values
$NDSum_{232xx} = \Sigma NegDifn,m$	Eq. 22	were computed)

An understanding of the operations described by Equations 15-22 is facilitated by FIG. 27, in which regular subarrays **230A-230Y** and offset subarrays **232A-232JJ** are sized to have four pixel values PVn,m_E per side for purposes of example. It will be understood that for most subarrays **230A-230Y** and **232A-232JJ** (those which do not include pixel values PVn,m_E in the top or bottom rows or rightmost column), difference values HorizDifn,m, VertDifn,m, PosDifn,m, and NegDifn,m for all pixel values PVn,m_E within the subarray will have been computed and will be summed. However, for those subarrays which have pixel values PVn,m_E in the top or bottom rows or rightmost column of illumination equalized array IEA, not all of the pixel values therein will have had difference values HorizDifn,m, VertDifn,m, PosDifn,m, and NegDifn,m, computed therefor. As a result, only those pixel values PVn,m_E for which difference values were computed can be summed to contribute to difference value sums HDSum, VDSum, PDSum and HDSum of subarrays **230A-230Y** and **232A-232JJ**. As an example, for offset subarray **232A** in FIG. 27, only pixel value $PV2,2_E$ had difference values computed therefor.

Following the above description, $HDSum_{232A}$=-HorizDif2,2, $VDSum_{232A}$=VertDif2,2, $PDSum_{232A}$=-PosDif2,2, and $NDSum_{232A}$=NegDif2,2. Also by way of example, for regular array **230A**, $HDSum_{230A}$=-HorizDif2,2+HorizDif2,3+HorizDif2,4+HorizDif 3,2+HorizDif3,3+HorizDif3,4+HorizDif4,2+HorizDif4,3+HorizDif4,4.

Computer **200** next determines the dominant direction of each regular subarray **230A-230Y** and offset subarray **232A-232JJ** as a function of the difference value sums of that subarray. In particular, the dominant direction for a subarray **230xx** is the direction or orientation associated with the lesser of $HDSum_{230xx}$, $VDSum_{230xx}$, $PDSum_{230xx}$ or $NDSum_{230xx}$ of that subarray **230xx**. Similarly, the dominant direction of an offset subarray **232xx** is the direction associated with the lesser of $HDSum_{232xx}$, $VDSum_{232xx}$. $PDSum_{232xx}$, or $NDSum_{232xx}$. In those cases in which more than one of the difference value sums are equal, the dominant direction is that direction which is 90° offset from the direction characterized by the greatest difference value sum.

Having determined the dominant directions, computer **200** performs a directional filter of each pixel value PVn,m_E of image array IEA as a function of a weighted average of the particular pixel value and adjacent pixel values in the dominant direction the subarrays **230A-230Y**, **232A-232JJ** of which the particular pixel value is an element.

A preferred embodiment of this directional filtering is best described as follows. First, each pixel value PVn,m_E is directional filtered as a function of the dominant direction of the regular subarray **230A-230Y** of which it is a member to provide a regular subarray directional filtered pixel value $RSPVn,m_E$. Second, each pixel value is directional filtered as a function of the dominant direction of the offset subarray **232A-232JJ** to provide an offset subarray directional filtered pixel value $OSPVn,m_E$ of which it is a member. Finally, the regular subarray directional filtered pixel value $RSPVn,m_E$ and offset subarray directional filtered pixel value $OSPVn,m_E$ are averaged to generate the corresponding directional filtered pixel value PVn,m_D of directional filtered array DFA.

Preferred weighted average formulas for generating regular subarray directional filtered pixel values $RSPVn,m_E$ for a particular pixel value PVn,m_E are described by equations 23-26.

$RSPVn,m_E =$	$(2\,PVn,m_E + PVn,m-1_E + PVn,m+1_E)/4$ (when the dominant direction of the regular subarray is horizontal)	Eq. 23
$RSPVn,m_E =$	$(2\,PVn,m_E + PVn-1,m_E + PVn+1,m_E)/4$ (when the dominant direction of the regular subarray is vertical).	Eq. 24
$RSPVn,m_E =$	$(2PVn,m_E + PVn-1,m+1_E + PVn+1,m-1_E)/4$ (when the dominant direction of the regular subarray is positive slope).	Eq. 25
$RSPVn,m_E =$	$(2PVn,m_E + PVn-1,m-1_E + PVn+1,m+1_E)/4$ (when the dominant direction of the regular subarray is negative slope).	Eq. 26

Offset subarray directional filtered pixel values $OSPVn,m_E$ can be computed in a similar manner using equations 27-30.

$OSPVn,m_E =$	$(2PVn,m_E + PVn,m-1_E + PVn,m+1_E)/4$ (if the dominant direction of the offset subarray is horizontal).	Eq. 27
$OSPVn,m_E =$	$(2PVn,m_E + PVn-1,m_E + PVn+1,m_E)/4$ (if the dominant direction of the offset subarray is vertical).	Eq. 28
$OSPVn,m_E =$	$(2PVn,m_E + PVn-1,m+1_E + PVn+1,m-1_E)/4$ (if the dominant direction of the offset subarray is positive slope).	Eq. 29
$OSPVn,m_E =$	$(2PVn,m_E + PVn-1,m-1_E + PVn+1,m+1_E)/4$ (if the dominant direction of the offset subarray is negative slope).	Eq. 30

Directional filtered pixel values PVn,m_D are generated by computer **200** by averaging corresponding regular subarray pixel values $RSPVn,m_E$ and offset subarray pixel values $OSPVn,m_E$. The procedure is described mathematically by Equation 31.

$$PVn,m_D=(RSPVn,m_E+OSPVn,m_E)/2 \quad \text{Eq. 31}$$

Following the above-described procedure, computer 200 can generate a directional filtered array DFA of directional filtered pixel values PVn,m_D as illustrated in FIG. 25. For pixel values PVn,m_E in the top and bottom rows and rightmost column of illumination equalized array IEA which are not directional filtered, computer 200 sets their corresponding directional filtered pixel value equal to their illumination equalized pixel value, as described by equation 32 below. This procedure will not materially affect the image represented by directional filtered array DFA since these pixel values are on the edges.

$$PVn,m_D = PVn,m_E \text{ for: } \begin{array}{l} n = 1, 1 \leq m < M \\ n = N, 1 \leq m < M \\ 1 \leq n \leq N, m = M \end{array} \quad \text{Eq. 32}$$

D. Unhair

The fingerprint image represented by directional filtered array DFA will typically include artifacts of "hairs" which are undesirable noise components of the image. Artifacts such as 240 are shown within fingerprint image 242 in FIG. 28. As is evident from FIG. 28, artifacts 240 typically are finer than or have a width which is less than either valleys 138 or ridges 136 of the fingerprint image. To enhance the image represented by directional filtered array DFA, computer 200 "unhairs" the image by processing this array in accordance with an Unhair program stored within ROM 204. The result is an artifact removed or unhaired array UA of unhaired pixel values PVn,m_U illustrated in FIG. 29.

The Unhair program implemented by computer 200 operates on the assumption that artifacts 240 will have a width which is less than the width of either valleys 138 or ridges 136 of a fingerprint image such as 242 illustrated in FIG. 28 (as represented by directional filtered array DFA). It is therefore assumed that the width of valleys 138 and ridges 136 will occupy a minimum number of adjacent pixel locations PLn,m of directional filtered array DFA, while the width of an artifact 240 will occupy less than the number of adjacent pixel locations of a valley or ridge. A graphic representation of a portion of directional filtered array DFA illustrating a valley 138 and artifact 240 is illustrated in FIG. 30. It must be understood that the shading in FIG. 30 is merely for purposes of illustration, and is actual representative of the magnitude of pixel values PVn,m_D at the corresponding pixel locations PLn,m. In FIG. 30, artifact 240 is vertically oriented and has a width of two pixel locations PLn,m, while valley 138 has a minimum width of five "occupied" pixel locations PLn,m.

Data representative of the width of artifacts 240 that it is desired to remove, in terms of a number W of adjacent pixel locations PLn,m this width would occupy, is stored in RAM 202 or ROM 204. In one embodiment, it is assumed that a vertical "feature" of fingerprint image 242 which has a width less than W equals two pixel locations PLn,m is an artifact 240. Any vertically oriented features which are not more than W pixel locations PLn,m wide are deemed to be artifacts 240, and the pixel values PVn,m_D representing these features are unconditionally set to a value of PVMAX so as to eliminate these features from the image.

Following the Unhair program to eliminate vertically oriented artifacts 240, computer 200 processes groups of W+2 horizontally adjacent pixel values PVn,m_D of directional filtered array DFA, i.e., $PVn,m-1_D$, PVn,m_D, $PVn,m+1_D$, . . . $PVn,m+W_D$. Each of these pixel values must be compared to an unhair threshold value UT to determine if it is representative of a dark portion image 242 (i.e., a valley 138 or artifact 240), or a light portion (i.e., a ridge 136). Pixel values PVn,m_D which are less than threshold value UT are deemed to represent dark portions of image 242, while those greater than or equal to threshold value UT are deemed to represent light portions of the image. Threshold value UT can be stored in RAM 204, and be equal to (PVMAX−PVMIN)/2.

Computer 200 first looks to a group of W horizontally adjacent pixel values PVn,m to PVn,m+(W−1). If each of these values is less than the threshold value UT, then they are known to represent a dark feature of image 242. If this feature is a fingerprint valley 138, then one of the pixel values PVn,m adjacent to this group (i.e., one of PVn,m−1 or PVn,m+W) will also be dark, i.e., less than threshold UT. If this is the case, then the corresponding unhaired pixel value PVn,m_U is set to the value of its corresponding directional filtered pixel value PVn,m_D. This relationship is mathematically described by Equation 32a below.

If the group of W adjacent pixel values PVn,m to PVn,m+(W−1) are all less than the threshold UT but both adjacent pixel values PVn,m−1 and PVn,m+W are greater than or equal to the threshold UT, the group of W adjacent pixel values represent an artifact, and computer 200 sets all pixel values $PVn,m-1_U$ to $PVn,m+W_U$ equal to PVMAX, thereby eliminating the artifact from the image. This relationship is mathematically described by Equation 32b and takes precedence over equation 32a. That is, a pixel value PVn,m_U initially set in accordance with equation 32a can subsequently be set to PVMAX in accordance with equation 32b.

Finally, computer 200 will set pixel values PVn,m_U equal to the corresponding value PVn,m_D in directional filtered array DFA if not all W adjacent pixels PVn,m to PVn,m+(W−1) of the group are less than threshold UT. This relationship is described mathematically by equation 32a. Once the above procedure has been implemented for all pixel values PVn,m for $1 \leq n \leq N$, $2 \leq m \leq M-W$, an unhaired array UA is generated. The Unhair program is not performed on edge pixel values PVn,m_D for $1<n<N$, $M-W<m \leq M$. For these pixel values, PVn,m_U are set equal to PVn,m_D in accordance with Equation 32c.

For each PVn,m for $1 \leq n \leq N$, $2 \leq m \leq M-W$. If PVn,m_D and $PVn,m+1_D$ . . . and $PVn,m+(W-1)_D<UT$ and: $PVn,m-1_D$ or $PVn,m+W_D<UT$

or if any of PVn,m_D, $PVn,m+1_D$, . . . $PVn,m+(W-1)_D>UT$ then:

$$PVn,m_U=PVn,m_D \quad \text{Eq. 32a}$$

If PVn,m_D and $PVn,m+1_D$, . . . and $PVn,m+(W-1)_D<UT$ and: $PVn,m-1_D$ and $PVn,m+W_D \geq UT$ then:

$$PVn,m-1_D, PVn,m_D, \ldots \text{ and } PVn,m+W_D=PVMAX \quad \text{Eq. 32b}$$

$$PVn,m_U=PVn,mp_D \text{ for } 1<n<N,\ M-W<m \leq M. \quad \text{Eq. 32c}$$

Horizontally oriented artifacts can be removed in a similar manner using groups of W vertically adjacent pixel values PVn,m_D. However, experience has shown most artifacts **240** to be vertically oriented.

E. Curvature Correction

As previously discussed, since finger prisms **20A–20D** provide fingerprint images which are taken at an observation angle OA with respect to a longitudinal axis **139** of finger **132** (FIG. **15**), those portions of the fingerprint which are positioned adjacent one another about an X-base curve axis **140** at any given point about the longitudinal axis and which would be linearly positioned with respect to one another in a rolled fingerprint image, will actually be projected in such a manner as to appear to be curved in an upwardly arced manner within unhaired array UA. Computer **200** processes pixel vales PVn,m_U of unhaired array UA in accordance with a Curvature Correction program to produce a curvature corrected array CCA (FIG. **31**) of curvature corrected pixel values PVn,m_C which characterize the fingerprint image in a curvature corrected manner. Basically, the Curvature Correction program causes unhaired pixel values PVn,m_U to be translated vertically in position in acordance with tabulated curvature correction data characteristic of the curvature inherent in images provided by prisms **20A–20D**.

Curvature correction data is generated by computer **200** through the use of a flexible template **250** as illustrated in FIG. **32**. As shown, template **250** has a linear pattern of indicia **252** which can include a line **254** and hatch marks **256A–256G** at known and preferably evenly spaced locations thereabout. Template **250** is shaped in such a manner as to correspond to the curvature of the finger, with line **254** oriented perpendicular to an imaginary axis **139** representing the longitudinal axis of finger **132**. Line **254** will therefore be parallel to an X-base curve axis **140** of finger **132**. Shaped template **250** is then positioned within groove **102** of prism **20A** with pattern of indicia **252** oriented in the above-identified manner. As a result of the optical transfer function of prism **20A**, the image of line **254** propagated from face **106** of prism **20A** will be shaped in the form of an arc opening upward. A graphical illustration of this image as represented by template image array TIA is shown in FIG. **34**. Although line **254** is graphically illustrated in FIG. **34**, it is to be understood that the shading is actually represented by the magnitude pixel values PVn,m_T at the particular pixel locations.

Curvature correction data is generated from template image array TIA in the following manner. All curvature distortion inherent in the transfer function of prism **20A** occurs along a y-axis parallel to a vertical line through the longitudinal axis of the finger when positioned in groove **102** of prism **20A** (and generally parallel to surface **106**). Furthermore, it is assumed that all pixel values PVn,m for any column $1 \leqq m \leqq M$ within template image array TIA are distorted by the same amount. That is, the amount of distortion for all pixel values $PV1 \leqq n \leqq N,M$, for example, are equal.

Were line **254** undistorted by the optical properties of prism **20A**, the pixel values PVn,m representing line **254** (e.g., $PV2,1_T$, $PV2,2_T$, $PV3,3_T$, $PV3,4_T$) would all be adjacent one another in the same row (e.g., n=9) within template image array TIA. Curvature correction data for pixel values PVn,m_T for each column $1 \leqq m \leqq M$ can therefore be defined in terms of an offset OFFm from an expected position, where m is the column within array TIA. For purposes of example, it will be assumed that all of the pixel values illustrated in FIG. **34** which represent line **254** should actually be positioned in row n=9. Offsets OFFm can be expressed in terms of the number of pixel locations PLn,m by which the pixel value PVn,m_T is vertically displaced from its proper location (e.g. row n=9). Using the example shown in FIG. **32**, **OFF1** and **OFF2** equal seven, **OFF3** and **OFF4** equal six and **OFF9** and **OFF10** equal three. Following this procedure, a curvature correction table of curvature correction or offset data **OFF1**–OFFM (illustrated in FIG. **33** for array TIA shown in FIG. **34**) is generated by computer **200** and stored in RAM **202** or ROM **204**.

Computer **200** utilizes the offset data in the curvature correction table to generate curvature corrected array CCA of curvature corrected pixel values PVn,m_C from unhaired array UA. Computer **200** does this by determining pixel values PVn,m_C of curvature corrected array CCA as a function of the pixel values PVn,m_U in the unhaired array and offsets OFFm, as described by equation 33, below.

$$PVn,m_C = PVn - OFFm,m_U \qquad \text{Eq. 33.}$$

Using the offsets of the example illustrated in FIG. **32** and described above and in the table illustrated in FIG. **33**, for example, $PV9,1_C = PV9-7,1_U = PV2,1_U$, $PV9,9_C = PV9-3,9_U = PV6,9_U$. Similarly $PV10,9_C = PV7,9_U$.

Following the above procedur a curvature corrected array CCA of curvature corrected pixel values PVn,m_C can be produced. For those pixel values PVn,m_C for $1 \leqq n < OFFm$ of a given row $1 \leqq m \leqq M$ of curvature corrected array CCA there will obliously be no pixel values PVh,m_U within unhaired array VA to "translate." These pixel values PVn,m_C are simply set equal to PVMAX or PVMIN, as they define the edge of the fingerprint image represented by array CCA.

The above procedure has been described for finger prism **20A**. However, due to the different characteristics of groove **102** of prisms **20A–20D**, a separate table of curvature correction data such as that illustrated in FIG. **33** will be generated by computer **200** for each prism. Computer **200** will then utilize the table of curvature correction data corresponding to the particular prism **20A–20D** from which the image being processed was propagated, to curvature correct the unhaired array UA representative of the image.

F. Vertical Scaling

As previously discussed, fingerprint images produced by finger prisms **20A–20D** and slap print prisms **18** and **18'** will have vertical or Y-axis size or scale errors due to the observation OA at which fingerprint **134** of finger **132** is imaged (FIG. **15**). This vertical scale error is compounded on fingerprint images produced by finger prisms **20A–20D** since portions of fingerprint **134** near tip **145** curve upward, effectively increasing the observation angle at these locations. This vertical scale error can also be thought of a paralax error. Since the image is taken at an angle other than 90° with respect to the "plane" of the fingerprint, true distances along Y-axis **141** which are parallel to the longitudinal axis **139** of finger **132** are "compressed", along the vertical axis of the fingerprint image such as that represented by curvature corrected array CCA. In other portions of the image, distances about Y-axis **141** can be "expanded" from their true distance on the fingerprint.

To correct those vertical scale errors, computer **200** processes curvature corrected array CCA in accordance with a Vertical Scaling program to generate a vertically scaled array VA of vertically scaled pixel values PVn,m_V as illustrated in FIG. **35**. A table of vertical scale correction data is generated for each prism **20A–20D**, **18** and **18'** within system **10**, and stored in either RAM **202** or ROM **204**. Computer **200** utilizes the table of vertical scale correction data to generate vertically scaled array VA.

The generation of the table of vertical scale correction data for prism **18** (which is representative of a generation of vertical scaling correction data for prisms **20A–20D** and **18'**) is described with reference to FIG. **36**. As shown, a template **270** will have a pattern of indicia **272A–272H** which are spaced about a Y-axis **274** by known and preferably equal distances D30. Template **270** is positioned on finger-receiving surface **150** of prism **18** with axis **274** oriented parallel to a longitudinal axis such as **139** of a finger such as **132** when positioned on prism **18**. An image **276** of the pattern of indicia **272A–272H** will be propagated from image propagation surface **156**, imaged by camera **28** (FIG. **2**), and the data representative of this image processed by computer **200** in accordance with the various programs described above until a curvature corrected array CCA of image **276** is generated.

A portion of a curvature corrected array CCA representative of image **276** and the pattern of indicia **272A–272H** is illustrated diagramatically in FIG. **37**. Indicia **272A–272E** are illustrated graphically in FIG. **37** for purposes of example. However, it is to be understood that the magnitude of the image at the particular pixel locations of indicia **272A–272H** in curvature corrected array CCA are actually represented by pixel values PVn,m_C.

Since indicia **272A–272H** are separated by known distances on template **270**, these known distances would correspond to predetermined numbers of pixel location PLn,m in the vertical or "n" direction of curvature corrected array CCA. In the embodiment of template **270** illustrated in FIG. **36**, indicia **272A–272H** are separated by equal known distances D30. Were there no vertical scale error, the representation of each indicia **272A–272H** would be separated from each other in the vertical direction of array CCA by the same predetermined number (e.g., three) pixel locations PLn,m. However, due to the scale errors inherent in prism **18**, indicia **272A–272H** will be separated by differing numbers of pixel locations PLn,m. In the example shown in FIG. **37**, indicia **272A** and **272B** are compressed, separated by no pixel locations PLn,m, and adjacent to one another. Indicia **272B** and **272C** are also compressed, but not quite as much, and are separated by one pixel location PLn,m. Indicia **272D** and **272E**, on the other hand, are vertically expanded from their normal positional relationship, and separated by four pixel locations PLn,m.

A table **280** of vertical scale correction data generated by computer **200** is illustrated graphically in FIG. **38**. Data within table **280** characterizes locations of pixel values PVn,m_V in vertically scaled array VA as a function of the vertical location within curvature corrected array CCA at which the pixel value should be taken. With respect to FIG. **37**, for example, it is assumed that pixel values $PV200,m_C$ will be correctly positioned in the same row of vertically scaled array VA. That is, pixel values $PV200,m_V = PV200,m_C$. However, it is known that indicia **272B** should be spaced from **72A** by three pixel locations PLn,m in the example used above. Pixel values **PV201**,m_C of curvature corrected array CCA should therefore be positioned in row **204** of vertically scaled array VA. Table **280**, therefore, includes data which characterizes pixel values **PV204**,m_V as being equal to pixel values **PV201**,m_C of curvature corrected array CCA.

Since indicia **272A** and **272B** were compressed due to the optical transfer properties of prism **18**, information therebetween is lost. Computer **200** thereby "fills in" this lost information by inserting or repeating pixel values **PV201**,m_V–**PV203**,m_V of vertically scaled array VA with information at one of either pixel values **PV200**,m_C or **PV201**,m_C of the curvature corrected array CCA. In the embodiment shown in FIG. **38**, all pixel values **PV201**,m_V–**PV203**,m_V are set equal to pixel value **PV201**,m_C of curvature corrected array CCA.

Following the above example, it is also known that indicia **272C** should be spaced vertically from indicia **272B** by three pixel locations PLn,m. All pixel values **PV203**,m_C of the 203rd row in curvature corrected array CCA should therefore actually be positioned in the 208th row of vertically scaled array VA. Accordingly, computer **200** generates data within table **280** associating pixel values **PV203**,m_C of curvature corrected array CCA with pixel values **PV208**,m_V of the vertically scaled array VA. Portions of the image which were lost due to compression between indicia **272B** and **272C** are "filled in" by repeating pixel values **PV202**,m_C of the curvature corrected array CCA at pixel values **PV205**,m_V–**PV207**,m_V of vertically scaled array VA. Data characteristic of this filling in or repetition of pixel values is characterized in table **280**. Procedures similar to those described above are repeated for pixel value **PV212**,m_V of vertically scaled array VA which should actually be equal to pixel values **PV206**,m_C in curvature corrected array CCA.

Indicia **272D** and **272E** would also be separated by three pixel locations PLn,m were no vertical scaling errors inherent in prism **18**. However, indicia **272D** and **272E** have been "expanded" by the optical properties of prism **18**, and they are actually separated by four pixel locations PLn,m. In other words, pixel values **PV211**,m_C in curvature corrected array CCA should actually be spaced from pixel values **PV212**,m_V of vertical scaled array VA (which correspond to pixel values **PV206**,m_C in curvature corrected array CCA) by three pixel locations PLn,m. Accordingly, computer **200** causes data representative of the fact that pixel values **PV216**,m_V of vertically scaled array VA should actually be equal to pixel values **PV211**,m_C of curvature corrected array CCA in table **280**.

Since indicia **272D** and **272E** were expanded, portions of the image therebetween are redundant and must be eliminated. In this particular example, one row of pixel values PVn,m_C must be eliminated from the curvature corrected array CCA. In generating vertical scaling correction data in table **280**, computer **200** has eliminated pixel values **PV208**,m_C of curvature corrected array CCA.

The above procedure is carried out for all pixels **PV1**,m_V–**PVN**,m_V of vertically scaled array VA to generate vertical scale correction data in table **280** which characterizes the row within curvature corrected array CCA from which each row of pixel values PVn,m_V of vertically scaled array VA should be taken. It has been found, however, that by vertically scaling the image in this manner, that there will be no corresponding pixels PVn,m_C in curvature corrected array CCA which are properly translated to positions near the top and bottom edges of vertically scaled array VA. These portions of vertically scaled array VA, typically for rows n less than 100 and n greater than 400 for a 512 pixel array, are set equal to PVMAX so they will be represented as white in the output image. Computer **200** causes data representative of this inherent feature to be stored in table **280** of vertical scaling correction data as illustrated in FIG. **38**.

To generate vertically scaled array VA, computer **200** utilizes data stored in memory and representative of table **280** (vertical scale correction data) along with pixel values PVn,m_C of curvature corrected array CCA. For each pixel value PVn,m_V of vertically scaled array VA, computer **200** accesses table **280** to determine from which row of curvature corrected array CCA the pixel value PVn,m_C should be taken. For example, to produce a vertically scaled array VA from curvature corrected array CCA shown in FIG. **31** utilizing vertical scale correction data in table **280**, pixel values $PV200,m_V$ will be set equal to corresponding pixel values $PV200,m_C$ of curvature corrected array CCA. Pixel values $PV200,200_V$ of vertically scaled array VA will, for example, be set equal to pixel value $PV200,200_C$ of curvature corrected array CCA. Following a similar approach, pixel values $PV211,m_V$ of vertically scaled array VA will be said equal to corresponding pixel values $PV205,m_C$. Pixel value $PV211,200_V$ of vertically scaled array VA will, for example, be set equal to pixel value $PV205,200_C$ of curvature corrected array CCA. Utilizing the scaling data in table **280**, all pixel values $PV1,m_V$ and PVN,m_V are set equal to values PVMAX. Computer **200** will then store data representative of vertically scaled array VA in RAM **202**.

G. Horizontal Scaling

As previously discussed, fingerprint images produced by finger prisms **20A–20D** will have horizontal or X-axis size or scale errors due to the observation angle OA at which finger **134** of finger **132** is imaged, and the fact that portions of the fingerprint are positioned about a curved surface such as that represented by X-base curve axis **140** at sides **144** of fingerprint **143**. Since the image is taken at an observation angle other than 90° with respect to the "plane" of the fingerprint at any particular point, two distances along X-axis **140** are "compressed" along the horizontal axis of the fingerprint image such as that represented by vertically scaled array VA. In other portions of the image, distances about X-axis **140** can be "expanded" from their true distance on the fingerprint.

To correct for these horizontal scale errors, computer **200** processes vertically scaled array VA in accordance with a Horizontal Scaling program to generate a horizontally scaled array HA of horizontally scaled pixel values PVn,m_H as illustrated in FIG. **39**. A table **310** of vertical scale correction data such as that illustrated in FIG. **40** is generated for each prism **20A–20D** within system **10**, and stored in either RAM **202** or ROM **204**. Computer **200** utilizes the table such as **310** of horizontal scale correction data to generate horizontally scaled array HA.

The generation of a table **310** of horizontal scale correction data for prism **20A** (which is representative of generation of tables of horizontal scale correction data for prisms **20A–20D**) is described initially with reference to FIG. **32**. As shown in FIG. **32**, a template **250** has a pattern of indicia **252** which includes hatch marks **256A–256G** spaced about a line **254** by known and preferably equal distances. Template **250** is then shaped to conform to groove **102** of prism **20A**, and positioned within the group in such a manner that line **254** is perpendicular to a longitudinal axis of the groove. This procedure is performed in a manner identical to that previously described with reference to the Curvature Correction program. An image of pattern of indicia **252** and hatch marks **256A–256G** will be propagated from image propagation surface **106**, imaged by camera **28** (FIG. **2**), and data representative of this image processed by computer **200** in accordance with the various programs described above until a vertically scaled array VA of the image is generated.

A portion of vertically scaled array VA representative of the image of hatch marks **256A–256E** is illustrated diagrammatically in FIG. **41**. Indicia **256A–256E** are illustrated graphically in FIG. **41** for purposes of example. However, it is to be understood that the magnitude of the image at the particular pixel locations of indicia **256A–256E** in vertically scaled array VA are actually represented by pixel values PVn,m_V.

Since hatch marks **256A–256E** are separated by known distances on template **250**, these known distances would correspond to predetermined numbers of pixel locations PLn,m in the horizontal or "m" direction of vertically scaled array VA. In the embodiment of template **250** illustrated in FIG. **32**, hatch marks **256A–256G** are separated by known distances. Were there are no horizontal scale error, the representation of each hatch mark **256A–256G** would be separated from each other in the horizontal direction of array VA by the same predetermined number (e.g., three) pixel locations PLn,m. However, due to the scale errors inherent in prism **20A**, hatch marks **256A–256G** will be separated by differing numbers of pixel locations PLn,m. In the example shown in FIG. **41**, hatch marks **256A** and **256B** are compressed, separated by no pixel locations PLn,m, and adjacent to one another. Hatch marks **256B** and **256C** are compressed, but not quite as much, and are separated by one pixel location PLn,m. Hatch marks **256D** and **256E**, on the other hand, are horizontally expanded from their normal positional relationship, and separated by four pixel locations PLn,m.

Data within table **310** characterizes locations of pixel values PVn,m_H in horizontally scaled array HA as a function of the horizontal location within vertically scaled array VA at which the pixel value should be taken. With respect to FIG. **41**, for example, it is assumed that pixel values $PVn,300_V$ will be correctly positioned in the same row of the horizontally scaled array HA. That is, pixel values $PVn,300,_H = PVn,300_V$. However, it is known that hatch mark **256B** should be spaced from **256A** by three pixel locations PLn,m in the example used above. Pixel values $PVn,301_V$ of vertically scaled array VA should therefore be positioned in column **304** of horizontally scaled array HA. Table **310**, therefore, includes data which characterizes pixel values $PVn,304_H$ as being equal to pixel values $PVn,301_V$ of vertically scaled array VA.

Since hatch marks **256A** and **256B** were compressed due to the optical transfer properties of prism **20A**, information therebetween is lost. Computer **200** thereby "fills in" this lost information by inserting or repeating pixel values $PVn,301_H - PVn,303_H$ of horizontally scaled array HA with information at one of either pixel values $PVn,300_V$ or $PVn,301_V$ of the vertically scaled array VA. In table 310, all pixel values $PVn,301_H$–$PVn,303_H$ are set equal to pixel values $PVn,301_V$ of vertically scaled array VA.

Following the above example, it is also known that hatch mark 256C should be spaced horizontally from hatch mark 256B by three pixel locations PLn,m. All pixel values $PVn,303_V$ of the 303rd column in the vertically scaled array VA should therefore actually be positioned in the 208th column of horizontally scaled array VA. Accordingly, computer 200 generates data within table 310 associating pixel values $PVn,303_V$ of vertically scaled array VA with pixel values $PVn,308_H$ of the horizontally scaled array HA. Portions of the image which were lost due to the compression between hatch marks 256B and 256C are "filled in" by repeating pixel values $PVn,302_V$ of the vertically scaled array VA at pixel values $PVn,305_H$–$PVn,307_H$ of horizontally scaled array HA. Data characteristic of this filling in or repetition of pixel values is characterized in table 310. Procedures similar to those described above are repeated for pixel values $PVn,312_H$ of horizontally scaled array HA which should actually be equal to pixel values $PVn,306,_V$ of the vertically scaled array VA.

Hatch marks 256D and 256E would also be separated by three pixel locations PLn,m were no vertical scaling errors inherent in prism 20A. However, hatch marks 256D and 256E have been "expanded" by the optical properties of prism 20A, and they are actually separated by four pixel locations PLn,m. In other words, pixel values $PVn,311,_V$ in vertically scaled array VA should actually be spaced from pixel values $PVn,312_H$ of horizontally scaled array HA (which correspond to pixel values $PVn,306_V$ in vertically scaled array VA) by three pixel locations PLn,m. Accordingly, computer 200 causes data representative of the fact that pixel values $PVn,316,_H$ of horizontally scaled array HA should actually be equal to pixel values $PVn,311_V$ of vertically scaled array VA in table 310.

Since hatch marks 256D and 256E were expanded, portions of the image therebetween are redundant and must be eliminated. In this particular example, one column of pixel values PVn,m_V must be eliminated from the vertically scaled array VA. In generating horizontal scale correction data in table 310, computer 200 has eliminated pixel values $PVn,308_V$ of vertically scaled array VA.

The above procedure is carried out for all pixel values $PVn,1_H$–PVn,M_H of horizontally scaled array HA to generate horizontal scale correction data in table 310 which characterizes the column within vertically scaled array VA from which each column of pixel values PVn,m_H of horizontally scaled array HA should be taken. It has been found, however, that by horizontally scaling the image in this manner, that there will be no corresponding pixel values PVn,m_V which are properly translated to positions near the left and right edges of horizontally scaled array HA. These portions of horizontally scaled array HA, typically for columns m less than 100 and m greater than 400 for a 512 pixel array are set equal to PVMAX so that they will be represented as white in the output image. Computer 200 causes data representative of this inherent feature to be stored in table 310 of horizontal scale correction data as illustrated in FIG. 40.

To generate horizontally scaled array HA, computer 200 utilizes data stored in memory and representative of table 310 (horizontal scale correction data) along with pixel values PVn,m_V of vertically scaled array VA. For each pixel value PVn,m_H of horizontally scaled array HA, computer 200 accesses table 310 to determine from which column of vertically scaled array VA the pixel value PVn,m_H should be taken. For example, to produce horizontally scaled array HA from vertically scaled array VA shown in FIG. 35 utilizing horizontal scale correction data in table 310, pixel values $PVn,300_H$ will be set equal to corresponding pixel values $PVn,300_V$ of vertically scaled array VA. Pixel values $PV300,300_H$ of horizontally scaled array HA will, for example, be set equal to pixel value $PV300,300_V$ of vertically scaled array VA. Following a similar approach, pixel values $PVn,311_H$ of horizontally scaled array HA will be set equal to corresponding pixel values $PVn,305_V$. Utilizing the scaling data in table 310, all pixel values $PVn,1_H$ and PVn,M_H are set equal to values PVMAX. Computer 200 will then store data representative of horizontally scaled array HA and RAM 202.

H. Threshold

After the digital data representative of fingerprint 143 (FIG. 15) has been imaged by camera 28 and processed by computer 200 in accordance with the Noise Average, Illumination Equalization, Directional Filter, Unhair, Curvature Correction, and Vertical and Horizontal Scaling programs, a horizontally scaled array HA of horizontally scaled pixel values PVn,m_H representative of the fingerprint image is stored in RAM 202. Each pixel value PVn,m_H is an eight-bit digital value representing intensity of the image at that particular discrete or pixel location PLn,m. This data will be utilized by printer 16 to print an enhanced visual representation of the fingerprint image.

In one embodiment, printer 16 is a matrix printer capable of printing in a gray scale at discrete locations. When system 10 includes a printer 16 of this type, computer 200 retrieves pixel values PVn,m_H of horizontally scaled array HA from RAM 202, maps these pixel values into a proper format, and transmits this data to the printer. Printer 16 will then print a visual representation of the fingerprint image with the intensity at each discrete printed location determined by the pixel value PVn,m_H.

In another embodiment, printer 16 is a dot matrix printer, and incapable of utilizing pixel values PVn,m_H to print a gray scale image at discrete locations or dots. At each discrete location on applicant card 15, printer 16 can either leave the spot blank, or make it black. As a result, computer 200 implements a Threshold program to determine whether each pixel value PVn,m_H of the horizontally scaled array HA should be represented as a white or black spot by printer 16 on card 15.

Implementing the Threshold program, computer 200 compares each pixel value PVn,m_H to a print threshold value TP. If the pixel value PVn,m_H is less than the threshold value TP, this pixel value is to represent a "black" or printed region on applicant card 15, and computer 200 accordingly sets the pixel value to zero or "0". If the pixel value PVn,m_H is greater than or equal to threshold value TP, this particular pixel value is to represent a white portion of the image, and computer 200 accordingly sets a pixel value equal to one or "1". Threshold value TP can vary depending upon a desired appearance of the fingerprint image. In one embodiment, threshold value TP is a digital value representative of an intensity halfway between the two hundred and fifty-six (i.e. 128) possible intensity values which can be represented by eight-bit pixel values PVn,m_H. If it is desired to have the black portions of the printed fingerprint image (valleys **138**) to have a finer width, threshold value TP should be set to a value lower than 128. If it is desired to have the white portions of the image (ridges **136**) to have a finer width, threshold value TP should be set to a level higher than 128.

Having generated a Thresholded array of enhanced pixel values PVn,m_H, computer **200** stores these pixel values in RAM **202**. In response to print signals, computer **200** will transmit these bits sequentially in a standard printer format to printer **16**. In response, printer **16** will print the enhanced fingerprint image onto applicant card **15**.

System Operation

Operation of fingerprinting system **10** is described with reference to FIGS. **1** and **42–47**. Upon initial power-up, computer **200** will run a series of diagnostics which verify correct operation of computer **200**, RAM **202**, and ROM **204**. After passing these diagnostics, data terminal **6** will generate a copyright notice which will be displayed on monitor **7** for several seconds. Following the copyright notice, data terminal **6** will generate and display on its monitor **8** a Main Display menu **300** illustrated in FIG. **42**.

Having reviewed the available options presented on menu **300**, an operator can select Option 1 by sequentially pressing the "1" and RETURN keys of keyboard **7** of data terminal **6** whenever a new booking is being processed. System **10** is then cleared of information from a previous booking, and reset so as to be ready to accept new information.

If it is desired to initiate fingerprint capture or recording, the operator can select option 2 by sequentially pressing the "2" and RETURN keys of keyboard **7**. In response, data terminal **6** will generate and display Processing Choices menu **302** illustrated in FIG. **46**. Having reviewed the available options presnted on menu **302**, if the operator desires not to capture fingerprints, they will select Option 0 from menu **302** by sequentially pressing the "0" and RETURN keys of keyboard **7**. Data terminal **8** will then redisplay Main Display menu **300**. Should the operator desire to capture fingerprints, Option 1 from menu **302** will be selected by sequentially pressing the "1" and RETURN keys of keyboard **7**. Option 2 from menu **302** is selected if it is desired to capture only one fingerprint. This is done if it is desired to test system capabilities, or to edit a poor previously captured print. Option 2 is selected when the operator sequentially presses the "2" and RETURN keys of keyboard **7**.

If an operator desires to change capture options, Option 3 is selected by sequentially pressing the "3" and RETURN keys of keyboard **7**. In response to this option, the operator will be asked a series of questions by means of prompts displayed on monitor **8** of data terminal **6**. These questions are answered by pressing the "Y" key of keyboard **7** to answer "yes", or by pressing the "N" key to answer "no." Options which can be selected in this manner include a High Contrast Capture Option which allows a very quick capture of print, but with relatively low quality due to the high contrast. The operator can also get an enlarged printed copy of one of the prints if desired. If the Enlarged Print Option is selected, both a life-size and four times normal size image of a fingerprint can be printed by printer **16**. Also, the operator is asked if they would like to approve the print twice. The first chance to approve the print comes after capture, and the second chance comes after the image has been visually enhanced by the image enhancement software programs. Typically, prints are approved only once, that being after processing has been completed.

When Option 1 from menu **302** is selected, system **10** enters a capture mode during which all ten individual fingerprints, plus slap prints from both the left and right hands, will be captured. This procedure is implemented with the assistance of key pad **19** and display **13** on optics/processor unit **12**.

Having selected Option 1 from menu **302** when it is desired to capture fingerprints, computer **200** will first actuate motor **76** to drive slap/finger image selection optics **26** to the finger prism select position illustrated in FIG. **2** (if optics **26** is not already so positioned). Signals representative of this positioning are provided to computer **200** by microswitch **89**, where upon actuation of motor **76** is terminated. Computer **200** wil then cause LED **316A** of left hand indicia **312** to be lit, indicating a prompt that a fingerprint of the left thumb is to be captured. Simultaneously, computer **200** cause LEDs **21C** and **21D** to be lit, thereby illuminating keys **17C** and **17D**. The operator will then move trolley **42**, using lever **52**, to position a finger prism **20A–20D** having the properly sized groove **102** for the thumb of the particular person being fingerprinted within aperture **51**. The person being fingerprinted will then position their thumb within groove **102** of the selected prism **20A–20D**, and adjust their finger within the groove while the operator observes image quality on monitor **14**. When an image which it is desired to capture is displayed on monitor **14**, the operator will actuate CAPTURE key **17C** on key pad **19**. This image is then "frozen", with digitizer **206** digitizing the data provided by TV camera **24**. This data is then processed in accordance with the software programs described above to produce an array of data characterizing the enhanced fingerprint image. This data is then stored within RAM **202**. If the person being fingerprinted was an amputee and did not have a left thumb, the operator would have actuated AMP key **17D**. Computer **200** then stores data characteristic of this action.

If the "approve print twice" option was previously selected, the operator can further examine the image on monitor **14** prior to its being processed. If this option was selected, computer **200** will cause LEDs **21A** and **21B** to be lit, illuminating keys **17A** and **17B** to indicate that one of these keys is the correct response. If it is desired to continue processing this image, YES key **17A** is actuated. If after further study, it is decided that this image is not acceptable, NO key **17B** is actuated.

After the capture and processing of the left thumb fingerprint, computer **200** will cause LED **316B** to be illuminated thereby prompting the operator that the left index finger is to be fingerprinted. The above described procedures are then repeated, with prompts for each of the ten fingers of the two hands of the person being fingerprinted being made.

After all ten fingers have been individually fingerprinted in the above-described manner, a prompt will be displayed on monitor **8** of data terminal **6** indicating that slap or plain prints for the left hand are to be taken. Computer **200** will also actuate motor **76** so as to drive mounting plate **60** to its slap print image selection position. Computer **200** will receive a signal from microswitch **87**, and deactivate motor **76**, when selection optics 26 are properly positioned at the slap image position illustrated in FIG. 3B. CAPTURE key 17C and AMP key 17D will also be lit. The person to be fingerprinted will then position the index, middle, ring and little fingers of the left hand on finger receving surface 150 of slap print prism 18'. When the operator observes a high quality image on monitor 14, they will press CAPTURE key 17C which "freezes" this image, and causes it to be processed by the image enhancement software of processor subsystem 30. Data representative of this slap print image is then stored in RAM 202. This procedure is then repeated for the slap or plain prints of the right hand.

After the slap prints have been taken, Main Display menu 300 which is shown in FIG. 42 will again be displayed on monitor 8 of data terminal 6. The operator can then select Option 3 to enter demographic information regarding the person whose fingerprints have just been taken as well as to enter department information used by the police or other organization performing the fingerprinting. When Option 3 is selected, data terminal 6 will display on its monitor 8 a Demographic/Department Information menu such as 320 (FIG. 45) which requests the operator to enter all necessary demographic and department information. The operator can then enter this demographic information using the various keys of keyboard 7 of data terminal 6 in a standard manner. Main Display menu 300 can then again be displayed when the operator presses the RETURN key once all demographic and department information has been entered into terminal 6.

After all fingerprints have been captured and demographic/department information entered, the operator can select Option 4 to have all of this information printed on a standardized booking or applicant card such as 15 illustrated in FIG. 47. Applicant card 15 has standardized locations for all the various fingerprints which have been capured, as well as the demographic information and department information which has been entered into terminal 6. Card 15 will be inserted into printer 16 in an indexed manner. When Option 4 is selected, computer 200 causes all of the information retrieved from RAM 202 and to be printed at the proper locations on card 15.

Conclusion

In conclusion, the optical fingerprinting system of the present invention offers a number of significant advantages over those of the prior art. Both individual fingerprint and slap print images can be optically obtained. A real-time display of the fingerprint being imaged can be observed and analyzed prior to its capture. Grooves within the finger prisms are contoured in such a manner as to provide an optimum amount of contact between the fingerprint and the prism. The lens trolley, which has finger prisms with a variety of different sized grooves, permits use of the system with a wide range of finger sizes. The lensed surface of the finger and slap prisms reduces vertical and horizontal scale errors, as well as curvature correction errors. Furthermore, remaining scale and curvature errors are eliminated, and other characteristics of the fingerprint image greatly enhanced, through the use of the Image Enhancement programs. The system is also designed to be very user friendly.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

```
                    Average - Aver[illegible] ixel with neighbors

Address Object      Statement

                           xdef     Average

        00000001           section 1



                           include macros.def         include macro definitions
        00000001           NOLIST
                           NOLIST

                           include global.def         include global symbol definitions
                    **     Global.def - global symbol definitions.
                    *
                    *      Copyright (C) 1986, CFA Technologies, Inc.


                    ****   Intensity level definitions.

        00000000    L0     equ     0
        00000010    L1     equ     16
        00000020    L2     equ     32
        00000030    L3     equ     48
        00000040    L4     equ     64
```

```
Address Object          Statement.
        00000050        L5      equ     80
        00000060        L6      equ     96
        00000070        L7      equ     112
        00000080        L8      equ     128
        00000090        L9      equ     144
        000000A0        L10     equ     160
        000000B0        L11     equ     176
        000000C0        L12     equ     192
        000000D0        L13     equ     208
        000000E0        L14     equ     224
        000000FF        L15     equ     255

                        ****    Useful constants.

        00000009        Yshift  equ     9               ; log 2 of X and Y coordinate bounds
        000001FF        Border  equ     (1<<(Yshift))-1 ; X and Y coordinate border

                        ****    Character constants.

        00000020        Space   equ     $20
        00000007        Bel     equ     'G'-$40
        00000008        BS      equ     'H'-$40
        00000009        Tab     equ     'I'-$40
        0000000A        LF      equ     'J'-$40
        0000000C        FF      equ     'L'-$40
        0000000D        CR      equ     'M'-$40
        0000000E        SO      equ     'N'-$40
        0000000F        SI      equ     'O'-$40
        00000011        Xon     equ     'Q'-$40
        00000013        Xoff    equ     'S'-$40
        0000001B        Esc     equ     '['-$40
        0000007F        Del     equ     $7f
        00000019        CtrlY   equ     'Y'-$40

                        ****    Constants used to control LEDs

                        * Legal codes for ButtonLight (SwitchOff also good for FingerLight)

        00000000        SwitchOff       equ     0
        00000001        YesAndNo        equ     1
        00000002        Capture         equ     2
        00000003        SwitchTest      equ     3

                        * Codes to control fluorescent lights

        00000001        FluorRoll       equ     1
        00000002        FluorSlap       equ     2



                        ****    Assembly constants.


                        **      Background fill value.
```

```
Address Object      Statement
        000000FF    BackFill        equ     L15             white


                    **      Assembly options.

        FFFFFFFF    StandardAverage equ     true            use (1,2,1) (2,4,2) (1,2,1) average
        00000000    HorizAverage    equ     false           use (0,0,0) (1,2,1) (0,0,0) average


                    ****



                    ***     Average - Average pixel with neighbors.
                    *       Original version by M. S. Ransom.
                    *       Implemented in 68000 assembly language and
                    *       modified to run without buffers by D. E. Germann.
                    *
                    *       entry   (a1.1) = address of input image screen buffer
                    *               NOTE: There MUST be free memory of size 2*(Border+1)
                    *                       bytes before the input screen image.
                    *
                    *       exit    (a1.1) = address of averaged image.
                    *
                    *       uses    a - 1.
                    *               d - none.
                    *
                    *       calls   none.

                    Average
1 000000 48E7F038           movem.l a2-a4/d0-d3,-(sp)       save registers
1 000004 2449               move.l  a1,a2
1 000006 95FC00000400       sub.l   #2*(Border+1),a2        compute address of output image
1 00000C 2649               move.l  a1,a3                   copy input and output pointers
1 00000E 284A               move.l  a2,a4
1 000010 D7FC000001FF       add.l   #Border,a3              set up for loop entry
1 000016 D9FC000001FF       add.l   #Border,a4
1 00001C 7600               moveq   #0,d3                   clear pixel register
1 00001E 323C01FD           move.w  #Border-2,d1            y := 1 to Border-1 (d1 counts down)
1 000022 303C01FD   avg1    move.w  #Border-2,d0            x := 1 to Border-1 (d0 counts down)
1 000026 548B               addq.l  #2,a3                   point counters at next line
1 000028 548C               addq.l  #2,a4
1 00002A 7400       avg2    moveq   #0,d2                   clear sum

                            ift     StandardAverage
                    +       IFNE    StandardAverage
1 00002C 1413               move.b  (a3),d2                 sum := 4 * pixel(x,y)
1 00002E D442               add.w   d2,d2
1 000030 162BFFFF           move.b  -1(a3),d3
1 000034 D443               add.w   d3,d2                     + 2 * pixel(x-1,y)
1 000036 162B0001           move.b  1(a3),d3
1 00003A D443               add.w   d3,d2                     + 2 * pixel(x+1,y)
1 00003C 162BFE00           move.b  -(Border+1)(a3),d3
1 000040 D443               add.w   d3,d2                     + 2 * pixel(x,y-1)
1 000042 162B0200           move.b  Border+1(a3),d3
```

```
Address Object          Statement.

1 000046 D443                   add.w   d3,d2                     + 2 * pixel(x,y+1)
1 000048 D442                   add.w   d2,d2
1 00004A 162BFDFF               move.b  0-1-(Border+1)(a3),d3
1 00004E D443                 - add.w   d3,d2                     + pixel(x-1,y-1)
1 000050 162BFE01               move.b  1-(Border+1)(a3),d3
1 000054 D443                   add.w   d3,d2                     + pixel(x+1,y-1)
1 000056 162B01FF               move.b  0-1+(Border+1)(a3),d3
1 00005A D443                   add.w   d3,d2                     + pixel(x-1,y+1)
1 00005C 162B0201               move.b  1+(Border+1)(a3),d3
1 000060 D443                   add.w   d3,d2                     + pixel(x+1,y+1)
1 000062 E84A                   lsr.w   #4,d2                   average := sum div 16
                                endc

                                ift     HorizAverage
                        +       IFNE    HorizAverage
                                move.b  (a3),d2                 sum := 2 * pixel(x,y)
                                add.w   d2,d2
                                move.b  -1(a3),d3
                                add.w   d3,d2                     + pixel(x-1,y)
                                move.b  1(a3),d3
                                add.w   d3,d2                     + pixel(x+1,y)
                                lsr.w   #2,d2                   average := sum div 4
                                endc
1 000064 18C2                   move.b  d2,(a4)+                store averaged pixel and advance
1 000066 528B                   addq.l  #1,a3                   advance to next input pixel
1 000068 51C8FFC0               dbra    d0,avg2                 do next pixel
1 00006C 51C9FFB4               dbra    d1,avg1                 do next raster line


                        **      Clear border areas that are garbage because average doesn't
                        *       operate on the whole image.

1 000070 70FF                   moveq   #(BackFill<<24)+(BackFill<<16)+(BackFill<<8)+BackFill,d0
1 000072 323C007F               move.w  #((Border+1)/4)-1,d1
1 000076 224A                   move.l  a2,a1
1 000078 22C0           avg3    move.l  d0,(a1)+                clear upper raster line
1 00007A 51C9FFFC               dbra    d1,avg3
1 00007E 323C007F               move.w  #((Border+1)/4)-1,d1
1 000082 224A                   move.l  a2,a1
1 000084 D3FC00040000           add.l   #((Border+1)*(Border+1)),a1
1 00008A 2300           avg4    move.l  d0,-(a1)                clear lower raster line
1 00008C 51C9FFFC               dbra    d1,avg4
1 000090 224A                   move.l  a2,a1
1 000092 323C01FF               move.w  #Border,d1
1 000096 1280           avg5    move.b  d0,(a1)                 clear left side
1 000098 134001FF               move.b  d0,Border(a1)           clear right side
1 00009C D2FC0200               add.w   #Border+1,a1            position to next raster line
1 0000A0 51C9FFF4               dbra    d1,avg5
1 0000A4 224A                   move.l  a2,a1                   return output buffer address in a1
1 0000A6 4CDF1C0F               movem.l (sp)+,a2-a4/d0-d3       restore registers and return
1 0000AA 4E75                   rts

                                end


0 errors detected.
```

Equalize - perfo[illegible] 'rea equalization on screer [illegible] ge.

```
Address Object      Statement.

                         xdef    Equalize

    00000001             section 1

                         include macros.def          include macro definitions
    00000001             NOLIST
                         NOLIST

                         include global.def          include global symbol definitions
                    **   Global.def - global symbol definitions.
                    *
                    *    Copyright (C) 1986, CFA Technologies, Inc.

                    **** Intensity level definitions.

    00000000        L0   equ     0
    00000010        L1   equ     16
    00000020        L2   equ     32
    00000030        L3   equ     48
    00000040        L4   equ     64
    00000050        L5   equ     80
    00000060        L6   equ     96
    00000070        L7   equ     112
    00000080        L8   equ     128
    00000090        L9   equ     144
    000000A0        L10  equ     160
    000000B0        L11  equ     176
    000000C0        L12  equ     192
    000000D0        L13  equ     208
    000000E0        L14  equ     224
    000000FF        L15  equ     255

                    **** Useful constants.

    00000009        Yshift  equ  9               ; log 2 of X and Y coordinate bounds
    000001FF        Border  equ  (1<<Yshift)-1   ; X and Y coordinate border

                    **** Character constants.

    00000020        Space   equ  $20
    00000007        Bel     equ  'G'-$40
    00000008        BS      equ  'H'-$40
    00000009        Tab     equ  'I'-$40
    0000000A        LF      equ  'J'-$40
    0000000C        FF      equ  'L'-$40
    0000000D        CR      equ  'M'-$40
    0000000E        SO      equ  'N'-$40
    0000000F        SI      equ  'O'-$40
```

```
Address Object    Statement.
        00000011  Xon     equ    'Q'-$40
        00000013  Xoff    equ    'S'-$40
        0000001B  Esc     equ    '['-$40
        0000007F  Del     equ    $7f
        00000019  CtrlY   equ    'Y'-$40

                  ****    Constants used to control LEDs

                  * Legal codes for ButtonLight (SwitchOff also good for FingerLight)

        00000000  SwitchOff     equ    0
        00000001  YesAndNo      equ    1
        00000002  Capture       equ    2
        00000003  SwitchTest    equ    3

                  * Codes to control fluorescent lights

        00000001  FluorRoll     equ    1
        00000002  FluorSlap     equ    2

                          include equalize.def          include Equalize's symbol definitions
                  **      Equalize.def - Equalize's symbol definitions.
                  *

        00000003  Grid          equ    3                size of left section of averaging grid



                  ****    Assembly options.

        00000000  LoopBackground  equ    false          use blankdist for background detection
        FFFFFFFF  AvgBackground   equ    true           use average for background detection

                  ****



                  ****    Assembly constants.

                  *       For area equalization.

        00000040  TotalDots     equ    (Grid+1+(Grid+1))*(Grid+1+(Grid+1))

                  *       For background detection using loop.

        00000010  BlankVal      equ    16               variation threshhold for background
        00000003  BlankDist     equ    Grid             how far to look for background

                  *       Background fill value for unequalized areas.

        000000FF  BackFill      equ    255              white
```

```
Address Object          Statement.

                        ****

                        ***     Equalize - perform area equalization on screen image.
                        *       Based on Pascal implementation by M. S. Ransom.
                        *       Converted to 68000 assembler by D. E. Germann.
                        *
                        *       Copyright (C) 1986, CFA Technologies, Inc.
                        *
                        *       entry   (a4.l) = input screen image address.
                        *               There MUST be free memory of size (Grid+1) * (Border+1)
                        *               before the input screen image.
                        *               (d0.w) = background level.
                        *
                        *       exit    image converted.
                        *               (a5.l) = output screen image address.
                        *
                        *       uses    a - 0, 1, 2, 3, 5, 6.
                        *               d - all.
                        *
                        *       calls   none.

                                VarBegin
        00000000        +Voffset set    0
                                var.w   Background,1
        FFFFFFFE        +       nolist
                                array.w ColumnSum,0,Border,1
        FFFFFBFE        +       nolist
                                VarEnd  EquRam
        FFFFFBFE        +       nolist

                        Equalize
1 000000 4E56FBFE               link    a6,#EquRam
1 000004 3D40FFFE               move.w  d0,Background(a6)       save background value
1 000008 2A4C                   move.l  a4,a5
1 00000A 9BFC00000800           sub.l   #(Grid+1)*(Border+1),a5 compute output image address
1 000010 7000                   moveq   #0,d0
1 000012 323C01FF               move.w  #Border,d1
1 000016 41EEFBFE               lea     ColumnSum(a6),a0
1 00001A 30C0           equ1    move.w  d0,(a0)+                ColumnSum[i] := 0
1 00001C 51C9FFFC               dbra    d1,equ1
1 000020 7206                   moveq   #Grid+(Grid+1)-1,d1     y := 0 (d1 counts down)
1 000022 204C                   move.l  a4,a0                   addr(ScreenIn[0,0])
1 000024 343C01FF       equ2    move.w  #Border,d2              x := 0 (d2 counts down)
1 000028 43EEFBFE               lea     ColumnSum(a6),a1
1 00002C 1018           equ3    move.b  (a0)+,d0                ScreenIn[x,y]
1 00002E D159                   add.w   d0,(a1)+                CS[x] := CS[x] + ScreenIn[x,y]
1 000030 51CAFFFA               dbra    d2,equ3
1 000034 51C9FFEE               dbra    d1,equ2
1 000038 7203                   moveq   #Grid,d1                y := grid
1 00003A 7C09                   moveq   #Yshift,d6
1 00003C 7604           equ4    moveq   #Grid+1,d3
1 00003E D641                   add.w   d1,d3                   y + grid+1
```

```
Address Object         Statement.
1 000040 EDA3                    asl.l    d6,d3                         convert to y-coordinate
1 000042 244C                    move.l   a4,a2
1 000044 D5C3                    add.l    d3,a2                         addr(ScreenIn[0,y+grid+1])
1 000046 343C01FF                move.w   #Border,d2                    x := 0 (d2 counts down)
1 00004A 41EEFBFE                lea      ColumnSum(a6),a0
1 00004E 101A             equ5   move.b   (a2)+,d0                      ScreenIn[x,y+grid+1]
1 000050 D158                    add.w    d0,(a0)+  ~                   CS[x] := CS[x] + ScreenIn[x,y+grid+1]
1 000052 51CAFFFA                dbra     d2,equ5
1 000056 2A3C00000020            move.l   #TotalDots/2,d5               sum := TotalDots div 2 (0.5 to round)
1 00005C 7606                    moveq    #Grid+(Grid+1)-1,d3           i := 0 (d3 counts down)
1 00005E 45EEFBFE                lea      ColumnSum(a6),a2
1 000062 DA5A             equ6   add.w    (a2)+,d5                      sum := sum + ColumnSum[i]
1 000064 51CBFFFC                dbra     d3,equ6
1 000068 45EEFC04                lea      ColumnSum+(Grid*2)(a6),a2          addr(ColumnSum[Grid])
1 00006C 2601                    move.l   d1,d3
1 00006E EDA3                    asl.l    d6,d3
1 000070 5683                    addq.l   #Grid,d3
1 000072 224C                    move.l   a4,a1
1 000074 D3C3                    add.l    d3,a1                         addr(ScreenIn[Grid,Y])
1 000076 2640                    move.l   a5,a3
1 000078 D7C3                    add.l    d3,a3                         addr(ScreenOut[Grid,y])
1 00007A 7403                    moveq    #Grid,d2                      x := grid
1 00007C DA6A0008         equ7   add.w    2*(Grid+1)(a2),d5             sum := sum + ColumnSum[X+grid+1]
1 000080 1011                    move.b   (a1),d0                       pixel := ScreenIn[x,y]

                                 ifne     LoopBackground
                                 moveq    #1,d3                         i := 1 (offset for x)
                                 move.w   #1<<Yshift,d4                 (offset for y)
                          equ8   neg.w    d4
                                 moveq    #0,d7
                                 move.b   0(a1,d4.w),d7                 ScreenIn[x,y-i]
                                 sub.w    d0,d7                         pixel - ScreenIn[x,y-i]
                                 bge.s    equ9
                                 neg.w    d7                            abs(pixel - ScreenIn[x,y-i])
                          equ9   cmp.w    #BlankVal,d7
                                 bgt.s    equ13                         if abs() > BlankVal
                                 neg.w    d4
                                 moveq    #0,d7
                                 move.b   0(a1,d4.w),d7                 ScreenIn[x,y+i]
                                 sub.w    d0,d7                         pixel - ScreenIn[x,y+i]
                                 bge.s    equ10
                                 neg.w    d7                            abs(pixel - ScreenIn[x,y+i])
                          equ10  cmp.w    #BlankVal,d7
                                 bgt.s    equ13                         if abs() > BlankVal
                                 neg.w    d3
                                 moveq    #0,d7
                                 move.b   0(a1,d3.w),d7                 ScreenIn[x-i,y]
                                 sub.w    d0,d7                         pixel - ScreenIn[x-i,y]
                                 bge.s    equ11
                                 neg.w    d7                            abs(pixel - ScreenIn[x-i,y])
                          equ11  cmp.w    #BlankVal,d7
                                 bgt.s    equ13                         if abs() > BlankVal
                                 neg.w    d3
                                 moveq    #0,d7
                                 move.b   0(a1,d3.w),d7                 ScreenIn[x+i,y]
```

```
Address Object          Statement
                                sub.w   d0,d7             pixel - ScreenIn[x+i,y]
                                bge.s   equl2
                                neg.w   d7                abs(pixel - ScreenIn[x+i,y])
                        equl2   cmp.w   #BlankVal,d7
                                bgt.s   equl3             if abs() > BlankVal
                                addq.w  #1,d3             i := i + 1 (offset for x)
                                add.w   #1<<Yshift,d4     (offset for y)
                                cmp.w   #BlankDist,d3
                                ble     equ8              if i <= BlankDist
                                moveq   #0,d3             BlankFlag := true
                                endc

1 000082 7EFF           equl3   moveq   #L15,d7           preload background for blank areas

                                ifne    LoopBackground
                                tst.b   d3
                                beq.s   equl4             if BlankFlag
                                endc

1 000084 2805                   move.l  d5,d4

                                ifeq    TotalDots-64
1 000086 EC4C                   lsr.w   #6,d4             average := sum div TotalDots
                                endc

                                ifne    TotalDots-64
                                  ifeq    TotalDots-256
                                  lsr.w   #8,d4           average := sum div TotalDots
                                  endc

                                  ifne    TotalDots-256
                                  divu    #TotalDots,d4   average := sum div TotalDots
                                  endc
                                endc

                                ifne    AvgBackground
1 000088 B86EFFFE               cmp.w   Background(a6),d4
1 00008C 6E16                   bgt.s   equl4             if average value is background
                                endc

1 00008E 3600                   move.w  d0,d3
1 000090 9644                   sub.w   d4,d3
1 000092 D67C0080               add.w   #L8,d3            pixel := pixel - average + L8
1 000096 B67C00FF               cmp.w   #L15,d3
1 00009A 6E08                   bgt.s   equl4             if pixel > L15 then pixel := L15
1 00009C 7E00                   moveq   #L0,d7            preload L0 in case pixel < L0

                                ifeq    L0
1 00009E 4A43                   tst.w   d3
                                endc

                                ifne    L0
                                cmp.w   #L0,d3
                                endc
```

```
Address Object         Statement.
 1 0000A0 6D02                    blt.s   equl4                  if pixel < L0 then pixel := L0
 1 0000A2 3E03                    move.w  d3,d7                  output pixel is OK as it is
 1 0000A4 16C7           equl4    move.b  d7,(a3)+               store output pixel
 1 0000A6 9A6AFFFA                sub.w   -2*Grid(a2),d5         sum := sum - ColumnSum[x-grid]
 1 0000AA 548A                    addq.l  #2,a2                  advance ColumnSum pointer
 1 0000AC 5289                    addq.l  #1,a1                  advance screen pointer
 1 0000AE 5242                    addq.w  #1,d2                  x := x + 1
 1 0000B0 B47C01FB                cmp.w   #Border-(Grid+1),d2
 1 0000B4 6FC6                    ble     equ7                   do next x value
 1 0000B6 76F0                    moveq   #-Grid,d3
 1 0000B8 D681                    add.l   d1,d3                  y-grid
 1 0000BA EDA3                    asl.l   d6,d3
 1 0000BC 224C                    move.l  a4,a1
 1 0000BE D3C3                    add.l   d3,a1                  addr(ScreenIn[0,y-grid])
 1 0000C0 45EEFBFE                lea     ColumnSum(a6),a2
 1 0000C4 343C01FF                move.w  #Border,d2             x := 0 (d2 counts down)
 1 0000C8 1019           equl9    move.b  (a1)+,d0
 1 0000CA 915A                    sub.w   d0,(a2)+               CS[x] := CS[x] - ScreenIn[x,y-grid]
 1 0000CC 51CAFFFA                dbra    d2,equl9
 1 0000D0 5241                    addq.w  #1,d1                  y := y + 1
 1 0000D2 B27C01FB                cmp.w   #Border-(Grid+1),d1
 1 0000D6 6F00FF64                ble     equ4                   do next y value

                         **       Clear border areas that are garbage because Equalize doesn't
                         *        operate on the whole image.

 1 0000DA 203CFFFFFFFF   equ20    move.l  #(BackFill<<24)+(BackFill<<16)+(BackFill<<8)+BackFill,d0
 1 0000E0 323C017F                move.w  #(((Border+1)/4)*(Grid))-1,d1
 1 0000E4 224D                    move.l  a5,a1
 1 0000E6 22C0           equ21    move.l  d0,(a1)+               clear upper raster lines
 1 0000E8 51C9FFFC                dbra    d1,equ21
 1 0000EC 323C01FF                move.w  #(((Border+1)/4)*(Grid+1))-1,d1
 1 0000F0 224D                    move.l  a5,a1
 1 0000F2 D3FC00040000            add.l   #((Border+1)*(Border+1)),a1
 1 0000F8 2300           equ22    move.l  d0,-(a1)               clear lower raster lines
 1 0000FA 51C9FFFC                dbra    d1,equ22
 1 0000FE 224D                    move.l  a5,a1
 1 000100 323C01FF                move.w  #Border,d1
 1 000104 7802           equ23    moveq   #Grid-1,d4
 1 000106 13804000       equ24    move.b  d0,0(a1,d4.w)          clear this line's left side
 1 00010A 51CCFFFA                dbra    d4,equ24
 1 00010E D2FC0200                add.w   #Border+1,a1           position to next raster line
 1 000112 7803                    moveq   #Grid,d4
 1 000114 7AFF                    moveq   #-1,d5
 1 000116 13805000       equ25    move.b  d0,0(a1,d5.w)          clear previous line's right side
 1 00011A 5345                    subq.w  #1,d5
 1 00011C 51CCFFF8                dbra    d4,equ25
 1 000120 51C9FFE2                dbra    d1,equ23
 1 000124 4E5E                    unlk    a6
 1 000126 4E75                    rts

                                  end

0 errors detected.
```

DirectionalFilter . Directional average.

Address Object Statement.

```
                          xdef    DirectionalFilter

00000001                  section 1



                          include macros.def          include macro definitions
00000001                  NOLIST
                          NOLIST

                          include global.def          include global symbol definitions
                   **     Global.def - global symbol definitions.
                   *
                   *      Copyright (C) 1986, CFA Technologies, Inc.


                   ****   Intensity level definitions.

00000000           L0     equ     0
00000010           L1     equ     16
00000020           L2     equ     32
00000030           L3     equ     48
00000040           L4     equ     64
00000050           L5     equ     80
00000060           L6     equ     96
00000070           L7     equ     112
00000080           L8     equ     128
00000090           L9     equ     144
000000A0           L10    equ     160
000000B0           L11    equ     176
000000C0           L12    equ     192
000000D0           L13    equ     208
000000E0           L14    equ     224
000000FF           L15    equ     255

                   ****   Useful constants.

00000009           Yshift equ     9                ; log 2 of X and Y coordinate bounds
000001FF           Border equ     (1<<(Yshift)-1   ; X and Y coordinate border

                   ****   Character constants.

00000020           Space  equ     $20
00000007           Bel    equ     'G'-$40
00000008           BS     equ     'H'-$40
00000009           Tab    equ     'I'-$40
0000000A           LF     equ     'J'-$40
0000000C           FF     equ     'L'-$40
0000000D           CR     equ     'M'-$40
0000000E           SO     equ     'N'-$40
0000000F           SI     equ     'O'-$40
00000011           Xon    equ     'Q'-$40
```

```
Address Object       Statement.
        00000013     Xoff     equ      'S'-$40
        0000001B     Esc      equ      '['-$40
        0000007F     Del      equ      $7f
        00000019     CtrlY    equ      'Y'-$40

                     ****     Constants used to control LEDs

                     * Legal codes for ButtonLight (SwitchOff also good for FingerLight)

        00000000     SwitchOff        equ     0 ~
        00000001     YesAndNo         equ     1
        00000002     Capture          equ     2
        00000003     SwitchTest       equ     3

                     * Codes to control fluorescent lights

        00000001     FluorRoll        equ     1
        00000002     FluorSlap        equ     2



                     ****     Assembly constants.


                     **       Tunable parameters.

        00000005     XGridLog         equ     5               log2(slope x-grid size)
        00000004     YGridLog         equ     4               log2(slope y-grid size)
        00000001     Step             equ     1               step distance when determining slopes
        000000FF     BackFill         equ     L15             background fill value (white)


                     **     - Derived constants.

        00000020     XGridSize        equ     1<<XGridLog     size of x-grid to determine line slopes
        00000010     YGridSize        equ     1<<YGridLog     size of y-grid to determine line slopes
        00000010     XOffset          equ     XGridSize/2     x-displacement for offset slope grid
        00000008     YOffset          equ     YGridSize/2     y-displacement for offset slope grid
        0000000F     LastXGrid        equ     Border/XGridsize  index of last slope x-grid
        0000001F     LastYGrid        equ     Border/YGridsize  index of last slope y-grid


                     ****



                     **       DirectionalFilter - Directional average to bitmap.
                     *        Based on Pascal design by M. S. Ransom.
                     *        Implemented in 68000 assembler and modified to run
                     *        without buffers by D. E. Germann.
                     *
```

```
Address Object          Statement.
                        *       entry   (a1.l) = address of input image screen buffer.
                        *               NOTE: there must be 2*(Border+1) bytes of free memory
                        *               in front of the input image screen buffer.
                        *
                        *       exit    (a1.l) = address of output image screen buffer.
                        *
                        *       uses    a - 1.
                        *               d - none.
                        *
                        *       calls   none.

                                VarBegin
        00000000        +Voffset set    0
                                Var.l           ScreenOut,1
        FFFFFFFC        +       nolist
                                Array2.l        GridTotal,-1,LastYGrid,-1,LastXGrid,4
        FFFFDE0C        +       nolist
                                Array2.l        OffTotal,-1,LastYGrid,-1,LastXGrid,4
        FFFFBAFC        +       nolist
                                Array2.b        Slopes,-1,LastYGrid,-1,LastXGrid,1
        FFFFB7BD        +       nolist
                                Array2.b        OffSlopes,-1,LastYGrid,-1,LastXGrid,1
        FFFFB58C        +       nolist
                                VarEnd          DirRam
        FFFFB57A        +       nolist

                        DirectionalFilter
1 000000 4E56B57A               link    a6,#DirRam
1 000004 48E7FFBC               movem.l a0/a2-a5/d0-d7,-(sp)    save registers
1 000008 2049                   move.l  a1,a0                   save input image address for later
1 00000A 2449                   move.l  a1,a2
1 00000C 94FC0400               sub.w   #2*(Border+1),a2        compute address of output image
1 000010 2D4AFFFC               move.l  a2,ScreenOut(a6)        save output image address

                        *       Initialize.

1 000014 7000                   moveq   #0,d0
1 000016 323C08C3               move.w  #((1+1+LastYGrid)*(1+1+LastXGrid)*4)-1,d1  longwords to clear
1 00001A 3401                   move.w  d1,d2
1 00001C 43EEDCEC               lea     GridTotal-(1*(1+1+LastXGrid)*(4*4))-(4*4)(a6),a1
1 000020 22C0           dir2    move.l  d0,(a1)+                GridTotal[*,*,*] := 0
1 000022 51C9FFFC               dbra    d1,dir2
1 000026 43EEB9DC               lea     OffTotal-(1*(1+1+LastXGrid)*(4*4))-(4*4)(a6),a1
1 00002A 22C0           dir3    move.l  d0,(a1)+                OffTotal[*,*,*] := 0
1 00002C 51CAFFFC               dbra    d2,dir3

                        *       Compute grid directional sums.

1 000030 7800                   moveq   #0,d4                   clear pixel register
1 000032 7401                   moveq   #1,d2                   y := 1
1 000034 2E02           dir4    move.l  d2,d7
```

```
Address Object          Statement.
1 000036 E847                    asr.w   #YGridLog,d7             GridY := y div YGridSize

                                 ifeq    LastXGrid-15
1 000038 3607                    move.w  d7,d3
1 00003A E947                    asl.w   #4,d7                    * 16
1 00003C DE43                    add.w   d3,d7                    GridY * (1 + 1 + LastXGrid)
                                 endc

                                 ifne    LastXGrid-15
                                 muls    #(1+1+LastXGrid),d7      GridY * (1 + 1 + LastXGrid)
                                 endc

1 00003E E987                    asl.l   #2+2,d7                  [GridY, 0]
1 000040 47EEDE0C                lea     GridTotal(a6),a3
1 000044 D7C7                    add.l   d7,a3                    addr(GridTotal[GridY, 0])
1 000046 7EF8                    moveq   #-YOffset,d7
1 000048 DE82                    add.l   d2,d7                    y - Yoffset
1 00004A E847                    asr.w   #YGridLog,d7             GridY2 := (y - YOffset) div YGridSize

                                 ifeq    LastXGrid-15
1 00004C 3607                    move.w  d7,d3
1 00004E E947                    asl.w   #4,d7                    * 16
1 000050 DE43                    add.w   d3,d7                    GridY2 * (1 + 1 + LastXGrid)
                                 endc

                                 ifne    LastXGrid-15
                                 muls    #(1+1+LastXGrid),d7      GridY2 * (1 + 1 + LastXGrid)
                                 endc

1 000052 E987                    asl.l   #2+2,d7                  [GridY2, 0]
1 000054 49EEBAFC                lea     OffTotal(a6),a4
1 000058 D9C7                    add.l   d7,a4                    addr(OffTotal[GridY2, 0])
1 00005A 99FC0010                sub.w   #4*4,a4                  addr(OffTotal[GridY2, -1])
1 00005E 7E09                    moveq   #Yshift,d7
1 000060 2602                    move.l  d2,d3
1 000062 EFA3                    asl.l   d7,d3                    convert y to coordinate offset
1 000064 2A48                    move.l  a0,a5
1 000066 DBC3                    add.l   d3,a5                    addr(ScreenIn[0, y])
1 000068 7200                    moveq   #0,d1                    x := 0
1 00006A 7C20                    moveq   #XGridSize,d6            grid counter for GridTotal
1 00006C 7E10                    moveq   #XGridSize/2,d7          grid counter for OffTotal
1 00006E 1015           dir5     move.b  (a5),d0                  pixel := ScreenIn[x, y]
1 000070 182D0001                move.b  1(a5),d4                 dot := ScreenIn[x+1, y]
1 000074 9840                    sub.w   d0,d4                    dot - pixel
1 000076 6C02                    bge.s   dir6
1 000078 4444                    neg.w   d4                       abs(dot - pixel)
1 00007A D99B           dir6     add.l   d4,(a3)+                 add to horizontal sum
1 00007C D99C                    add.l   d4,(a4)+
1 00007E 182D0201                move.b  1+(Border+1)(a5),d4      dot := ScreenIn[x+1, y+1]
1 000082 9840                    sub.w   d0,d4                    dot - pixel
1 000084 6C02                    bge.s   dir7
1 000086 4444                    neg.w   d4                       abs(dot - pixel)
1 000088 D99B           dir7     add.l   d4,(a3)+                 add to positive slope sum
```

```
Address Object          Statement.
1 00008A D99C                   add.l   d4,(a4)+
1 00008C 182D0200               move.b  Border+1(a5),d4          dot := ScreenIn[x, y+1]
1 000090 9840                   sub.w   d0,d4                    dot - pixel
1 000092 6C02                   bge.s   dir8
1 000094 4444                   neg.w   d4                       abs(dot - pixel)
1 000096 D99B           dir8    add.l   d4,(a3)+                 add to vertical sum
1 000098 D99C                   add.l   d4,(a4)+
1 00009A 182DFE01               move.b  1-(Border+1)(a5),d4      dot := ScreenIn[x+1, y-1]
1 00009E 9840                   sub.w   d0,d4                    dot - pixel
1 0000A0 6C000004               bge     dir9
1 0000A4 4444                   neg.w   d4                       abs(dot - pixel)
1 0000A6 D993           dir9    add.l   d4,(a3)                  add to negative slope sum
1 0000A8 D994                   add.l   d4,(a4)
1 0000AA 96FC000C               sub.w   #3*4,a3                  go back to start of array
1 0000AE 98FC000C               sub.w   #3*4,a4
1 0000B2 5241                   addq.w  #Step,d1                 x := x + Step
1 0000B4 528D                   addq.l  #Step,a5                 advance screen pointer
1 0000B6 5346                   subq.w  #Step,d6                 GTcounter := GTcounter - Step
1 0000B8 6E08                   bgt.s   dir9.1                   if more pixels in this grid
1 0000BA D6FC0010               add.w   #4*4,a3                  go to next array entry
1 0000BE DC7C0020               add.w   #XGridSize,d6            update GTcounter
1 0000C2 5347           dir9.1  subq.w  #Step,d7                 OTcounter := OTcounter - Step
1 0000C4 6E08                   bgt.s   dir9.2                   if more pixels in this grid
1 0000C6 D8FC0010               add.w   #4*4,a4                  go to next array entry
1 0000CA DE7C0020               add.w   #XGridSize,d7            update OTcounter
1 0000CE B27C01FE       dir9.2  cmp.w   #Border-1,d1
1 0000D2 6F9A                   ble     dir5                     if x <= (Border - 1)
1 0000D4 5242           dir10   addq.w  #Step,d2                 y := y + Step
1 0000D6 B47C01FE               cmp.w   #Border-1,d2
1 0000DA 6F00FF58               ble     dir4                     if y <= (Border - 1)

                        *       Determine line slopes.

1 0000DE 43EEDCEC       dir11   lea     GridTotal-(1*(1+1+LastXGrid)*(4*4))-(1*(4*4))(a6),a1  GT[-1,-1]
1 0000E2 45EEB9DC               lea     OffTotal-(1*(1+1+LastXGrid)*(4*4))-(1*(4*4))(a6),a2   OT[-1,-1]
1 0000E6 47EEB7AB               lea     Slopes-(1*(1+1+LastXGrid))-1(a6),a3       Slopes[-1,-1]
1 0000EA 49EEB57A               lea     OffSlopes-(1*(1+1+LastXGrid))-1(a6),a4   OffSlopes[-1,-1]
1 0000EE 7420                   moveq   #LastYGrid+1+1-1,d2      y := -1 to LastYGrid (d2 counts down)
1 0000F0 7210           dir12   moveq   #LastXGrid+1+1-1,d1      x := -1 to LastXGrid (d1 counts down)
1 0000F2 2619           dir13   move.l  (a1)+,d3                 min := GridTotal[y, x, Horizontal]
1 0000F4 7800                   moveq   #0*4,d4                  mindir := Horizontal
1 0000F6 2E19                   move.l  (a1)+,d7                 next := GridTotal[y, x, PositiveSlope]
1 0000F8 BE83                   cmp.l   d3,d7
1 0000FA 6C04                   bge.s   dir14                    if next >= min
1 0000FC 2607                   move.l  d7,d3                    min := next
1 0000FE 7804                   moveq   #1*4,d4                  mindir := PositiveSlope
1 000100 2E19           dir14   move.l  (a1)+,d7                 next := GridTotal[y, x, Vertical]
1 000102 BE83                   cmp.l   d3,d7
1 000104 6C04                   bge.s   dir15                    if next >= min
1 000106 2607                   move.l  d7,d3                    min := next
1 000108 7808                   moveq   #2*4,d4                  mindir := Vertical
1 00010A 2E19           dir15   move.l  (a1)+,d7                 next := GridTotal[y, x, NegativeSlope]
1 00010C BE83                   cmp.l   d3,d7
```

```
Address Object          Statement.
1 00010E 6C02                    bge.s   dir16                   if next >= min
1 000110 780C                    moveq   #3*4,d4                 mindir := NegativeSlope
1 000112 16C4           dir16    move.b  d4,(a3)+                Slopes[y, x] := mindir
1 000114 261A                    move.l  (a2)+,d3                min := OffTotal[y, x, Horizontal]
1 000116 7800                    moveq   #0*4,d4                 mindir := Horizontal
1 000118 2E1A                    move.l  (a2)+,d7                next := OffTotal[y, x, PositiveSlope]
1 00011A BE83                    cmp.l   d3,d7
1 00011C 6C04                    bge.s   dir17                   if next >= min
1 00011E 2607                    move.l  d7,d3                   min := next
1 000120 7804                    moveq   #1*4,d4                 mindir := PositiveSlope
1 000122 2E1A           dir17    move.l  (a2)+,d7                next := OffTotal[y, x, Vertical]
1 000124 BE83                    cmp.l   d3,d7
1 000126 6C04                    bge.s   dir18                   if next >= min
1 000128 2607                    move.l  d7,d3                   min := next
1 00012A 7808                    moveq   #2*4,d4                 mindir := Vertical
1 00012C 2E1A           dir18    move.l  (a2)+,d7                next := OffTotal[y, x, NegativeSlope]
1 00012E BE83                    cmp.l   d3,d7
1 000130 6C02                    bge.s   dir19                   if next >= min
1 000132 780C                    moveq   #3*4,d4                 mindir := NegativeSlope
1 000134 18C4           dir19    move.b  d4,(a4)+                OffSlopes[y, x] := mindir
1 000136 51C9FFBA                dbra    d1,dir13                do next x
1 00013A 51CAFFB4                dbra    d2,dir12                do next y

                        *        Average image.

1 00013E 226EFFFC                move.l  ScreenOut(a6),a1
1 000142 D1FC000001FF            add.l   #Border,a0              set up for loop entry
1 000148 D3FC000001FF            add.l   #Border,a1
1 00014E 7400                    moveq   #0,d2                   clear pixel register
1 000150 7201                    moveq   #1,d1                   y := 1
1 000152 2801           dir20    move.l  d1,d4
1 000154 E844                    asr.w   #YGridLog,d4            GridY := y div YGridSize

                                 ifeq    LastXGrid-15
1 000156 3A04                    move.w  d4,d5
1 000158 E944                    asl.w   #4,d4                   * 16
1 00015A D845                    add.w   d5,d4                   GridY * (1+1+LastXGrid) ( [GridY, 0] )
                                 endc

                                 ifne    LastXGrid-15
                                 muls    #(1+1+LastXGrid),d4     GridY * (1+1+LastXGrid) ( [GridY, 0] )
                                 endc

1 00015C 45EEB7BD                lea     Slopes(a6),a2
1 000160 D5C4                    add.l   d4,a2                   addr(Slopes[GridY, 0])
1 000162 78F8                    moveq   #-YOffset,d4
1 000164 D881                    add.l   d1,d4                   y - Yoffset
1 000166 E844                    asr.w   #YGridLog,d4            GridY2 := (y - Yoffset) div YGridSize

                                 ifeq    LastXGrid-15
1 000168 3A04                    move.w  d4,d5
1 00016A E944                    asl.w   #4,d4                   * 16
1 00016C D845                    add.w   d5,d4                   GridY2 * (1+1+LastXGrid) ( [GridY2, 0] )
```

```
Address Object          Statement.
                                endc

                                ifne    LastXGrid-15
                                muls    #(LastXGrid+1+1),d4     GridY2 * (1+1+LastXGrid) { [GridY2  0] }
                                endc

1 00016E 47EEB58C               lea     OffSlopes(a6),a3
1 000172 D7C4                   add.l   d4,a3                   addr(OffSlopes[GridY2, 0])
1 000174 534B                   subq.w  #1,a3                   addr(OffSlopes[GridY2, -1])
1 000176 7001                   moveq   #1,d0                   x := 1
1 000178 5488                   addq.l  #2,a0                   point input screen pointer at next line
1 00017A 5489                   addq.l  #2,a1                   point output screen pointer at next line
1 00017C 4BFA006A               lea     SideComp(pc),a5
1 000180 7E00                   moveq   #0,d7
1 000182 1E1A                   move.b  (a2)+,d7                main grid slope for this grid
1 000184 2C357000               move.l  0(a5,d7.w),d6           main grid component offsets
1 000188 7820                   moveq   #XGridSize,d4           grid counter for GridSlopes
1 00018A 1E1B                   move.b  (a3)+,d7                offset grid slope for this grid
1 00018C 2E357000               move.l  0(a5,d7.w),d7           offset grid component offsets
1 000190 7A10                   moveq   #XGridSize/2,d5         grid counter for OffSlopes
1 000192 B743           dir21   eor.w   d3,d3                   sum := 0
1 000194 1618                   move.b  (a0)+,d3
1 000196 D643                   add.w   d3,d3
1 000198 D643                   add.w   d3,d3                   sum := Screen[x, y] * 4
1 00019A 143060FF               move.b  -1(a0,d6.w),d2
1 00019E D642                   add.w   d2,d3                   add side one
1 0001A0 4846                   swap    d6
1 0001A2 143060FF               move.b  -1(a0,d6.w),d2
1 0001A6 D642                   add.w   d2,d3                   add side two
1 0001A8 143070FF               move.b  -1(a0,d7.w),d2
1 0001AC D642                   add.w   d2,d3                   add side one
1 0001AE 4847                   swap    d7
1 0001B0 143070FF               move.b  -1(a0,d7.w),d2
1 0001B4 D642                   add.w   d2,d3                   add side two
1 0001B6 5843                   addq.w  #8/2,d3                 add in rounding factor
1 0001B8 E64B                   lsr.w   #3,d3                   average := round(sum / 8)
1 0001BA 12C3                   move.b  d3,(a1)+                ScreenOut[x, y] := average
1 0001BC 5240                   addq.w  #1,d0                   x := x + 1
1 0001BE 5344                   subq.w  #1,d4                   GScounter := GScounter - 1
1 0001C0 6E08                   bgt.s   dir23.1                 if more pixels in this grid
1 0001C2 181A                   move.b  (a2)+,d4                slope for next grid
1 0001C4 2C3B4022               move.l  SideComp(pc,d4.w),d6    main grid component offsets
1 0001C8 7820                   moveq   #XGridSize,d4
1 0001CA 5345           dir23.1 subq.w  #1,d5                   OScounter := OScounter - 1
1 0001CC 6E08                   bgt.s   dir23.2                 if more pixels in this grid
1 0001CE 1A1B                   move.b  (a3)+,d5                slope for next grid
1 0001D0 2E3B5016               move.l  SideComp(pc,d5.w),d7    offset grid component offsets
1 0001D4 7A20                   moveq   #XGridSize,d5
1 0001D6 B07C01FE       dir23.2 cmp.w   #Border-1,d0
1 0001DA 6FB6                   ble.s   dir21                   if x <= (Border - 1)
1 0001DC 5241                   addq.w  #1,d1                   y := y + 1
1 0001DE B27C01FE               cmp.w   #Border-1,d1
1 0001E2 6F00FF6E               ble     dir20                   if y <= (Border - 1)
```

```
Address Object          Statement.
1 0001E6 6010                   bra.s   dir30                       clean up borders and exit


                        **      Side component offsets.
                        *

                        SideComp
1 0001E8 FFFF0001               dc.w    -1,1                                horizontal
1 0001EC FDFF0201               dc.w    0-1-(Border+1),1+(Border+1)         positive slope
1 0001F0 FE000200               dc.w    -(Border+1),Border+1                vertical
1 0001F4 01FFFE01               dc.w    0-1+(Border+1),1-(Border+1)         negative slope


                        **      Clear border areas that are garbage because directional
                        *       filter doesn't operate on the whole image.

1 0001F8 203CFFFFFFFF   dir30   move.l  #(BackFill<<24)+(BackFill<<16)+(BackFill<<8)+BackFill,d0
1 0001FE 323C007F               move.w  #((Border+1)/4)-1,d1
1 000202 226EFFFC               move.l  ScreenOut(a6),a1
1 000206 22C0           dir31   move.l  d0,(a1)+                    clear upper raster line
1 000208 51C9FFFC               dbra    d1,dir31
1 00020C 323C007F               move.w  #((Border+1)/4)-1,d1
1 000210 226EFFFC               move.l  ScreenOut(a6),a1
1 000214 D3FC00040000           add.l   #((Border+1)*(Border+1)),a1
1 00021A 2300           dir32   move.l  d0,-(a1)                    clear lower raster line
1 00021C 51C9FFFC               dbra    d1,dir32
1 000220 226EFFFC               move.l  ScreenOut(a6),a1
1 000224 323C01FF               move.w  #Border,d1
1 000228 1280           dir33   move.b  d0,(a1)                     clear left side
1 00022A 134001FF               move.b  d0,Border(a1)               clear right side
1 00022E D2FC0200               add.w   #Border+1,a1                position to next raster line
1 000232 51C9FFF4               dbra    d1,dir33
1 000236 4CDF3DFF               movem.l (sp)+,a0/a2-a5/d0-d7        restore registers
1 00023A 226EFFFC               move.l  ScreenOut(a6),a1            return output image address
1 00023E 4E5E                   unlk    a6
1 000240 4E75                   rts


                                end


0 errors detected.

                    Unhair - remove hairs from image.

Address Object          Statement.


                                xdef    Unhair


                                include macros.def                  macro definitions
        00000001                NOLIST
                                NOLIST

                                include global.def                  global symbol definitions
```

```
Address Object        Statement.
                      **      Global.def - global symbol definitions.
                      *
                      *       Copyright (C) 1986, CFA Technologies, Inc.


                      ****    Intensity level definitions.

        00000000      L0      equ     0
        00000010      L1      equ     16
        00000020      L2      equ     32
        00000030      L3      equ     48
        00000040      L4      equ     64
        00000050      L5      equ     80
        00000060      L6      equ     96
        00000070      L7      equ     112
        00000080      L8      equ     128
        00000090      L9      equ     144
        000000A0      L10     equ     160
        000000B0      L11     equ     176
        000000C0      L12     equ     192
        000000D0      L13     equ     208
        000000E0      L14     equ     224
        000000FF      L15     equ     255

                      ****    Useful constants.

        00000009      Yshift  equ     9               ; log 2 of X and Y coordinate bounds
        000001FF      Border  equ     (1<<(Yshift)-1  ; X and Y coordinate border

                      ****    Character constants.

        00000020      Space   equ     $20
        00000007      Bel     equ     'G'-$40
        00000008      BS      equ     'H'-$40
        00000009      Tab     equ     'I'-$40
        0000000A      LF      equ     'J'-$40
        0000000C      FF      equ     'L'-$40
        0000000D      CR      equ     'M'-$40
        0000000E      SO      equ     'N'-$40
        0000000F      SI      equ     'O'-$40
        00000011      Xon     equ     'Q'-$40
        00000013      Xoff    equ     'S'-$40
        0000001B      Esc     equ     '['-$40
        0000007F      Del     equ     $7f
        00000019      CtrlY   equ     'Y'-$40

                      ****    Constants used to control LEDs

                      * Legal codes for ButtonLight (SwitchOff also good for FingerLight)

        00000000      SwitchOff       equ     0
        00000001      YesAndNo        equ     1
        00000002      Capture         equ     2
        00000003      SwitchTest      equ     3

                      * Codes to control fluorescent lights
```

```
Address Object          Statement.
        00000001        FluorRoll       equ     1
        00000002        FluorSlap       equ     2

                                include section.def             section number definitions

                        ****    Section definitions.

        00000001        CodeSect        equ     1               code and pc-relative constants
        00000002        DataSect        equ     2               read/write data area
        00000003        RODataSect      equ     3               read only data area


                        ****    Assembly options.

        00000000        FillRidges      equ     false           fill in "holes" in ridges too

                        ****


        00000001                - section CodeSect


                        ***     Unhair - remove hairs from image.
                        *
                        *       Algorithm by G. M. Fishbine.
                        *       Implemented in 68000 assembly language by D. E. Germann.
                        *
                        *       Copyright (C) 1986, CFA Technologies, Inc.
                        *
                        *       entry   (a0.l) = screen buffer address.
                        *               (d0.w) = hair width in dots.
                        *               (d1.b) = black/white threshold.
                        *
                        *       exit    hairs removed from image
                        *               optionally (assembly time), ridge "holes" filled in, too
                        *
                        *       uses    a - none.
                        *               d - none
                        *
                        *       calls   none.

1 000000 48E7FF40       Unhair  movem.l a1/d0-d7,-(sp)
1 000004 1E01                   move.b  d1,d7           put threshold into a safe register
1 000006 3200                   move.w  d0,d1
1 000008 D241                   add.w   d1,d1           2n
1 00000A 3401                   move.w  d1,d2
1 00000C D440                   add.w   d0,d2
1 00000E 5342                   subq.w  #1,d2           3n-1
1 000010 283C000001FF           move.l  #Border,d4      y := Border downto 0
1 000016 2C04           unh1    move.l  d4,d6
1 000018 7609                   moveq   #Yshift,d3
1 00001A E7A6                   asl.l   d3,d6           convert y-coord to screen offset
1 00001C 2248                   move.l  a0,a1
1 00001E D3C6                   add.l   d6,a1           addr(Screen[0, y])
1 000020 363C01FF               move.w  #Border,d3
```

```
Address Object         Statement

1 000024 9642                   sub.w   d2,d3             x := 0 to Border-(3n-1) (d3 counts down)
1 000026 BE11           unh2    cmp.b   (a1),d7

                                ift     FillRidges
                        +       IFNE    FillRidges
                                bhi.s   unh4              if Screen[x, y] is a dark pixel
                                endc

                                iff     FillRidges
                        +       IFEQ    FillRidges
1 000028 625A                   bhi.s   unh8              if Screen[x, y] is a dark pixel
                                endc

1 00002A BE311000               cmp.b   0(a1,d1.w),d7
1 00002E 6254                   bhi.s   unh8              if Screen[x+2n, y] is a dark pixel
1 000030 7C01                   moveq   #1,d6             i := 1
1 000032 B046                   cmp.w   d6,d0
1 000034 6718                   beq.s   unh3.5            if n = 1, skip loops
1 000036 3A06                   move.w  d6,d5
1 000038 DA41                   add.w   d1,d5             i + 2n
1 00003A BE316000       unh3    cmp.b   0(a1,d6.w),d7
1 00003E 6244                   bhi.s   unh8              if Screen[x+i, y] is a dark pixel
1 000040 BE315000               cmp.b   0(a1,d5.w),d7
1 000044 623E                   bhi.s   unh8              if Screen[x+i+2n, y] is a dark pixel
1 000046 5246                   addq.w  #1,d6             i := i + 1
1 000048 5245                   addq.w  #1,d5             update i + 2n, too
1 00004A BC40                   cmp.w   d0,d6
1 00004C 6DEC                   blt.s   unh3              if i < n
1 00004E 7AFF           unh3.5  moveq   #L15,d5           filler := L15
1 000050 6026                   bra.s   unh6              make inner pixels match outer pixels

1 000052 BE311000       unh4    cmp.b   0(a1,d1.w),d7
1 000056 632C                   bls.s   unh8              if Screen[x+2n, y] is a light pixel
1 000058 7C01                   moveq   #1,d6             i := 1
1 00005A B046                   cmp.w   d6,d0
1 00005C 6718                   beq.s   unh5.5            if n = 1, skip loops
1 00005E 3A06                   move.w  d6,d5
1 000060 DA41                   add.w   d1,d5             i + 2n
1 000062 BE316000       unh5    cmp.b   0(a1,d6.w),d7
1 000066 631C                   bls.s   unh8              if Screen[x+i, y] is a light pixel
1 000068 BE315000               cmp.b   0(a1,d5.w),d7
1 00006C 6316                   bls.s   unh8              if Screen[x+i+2n, y] is a light pixel
1 00006E 5246                   addq.w  #1,d6             i := i + 1
1 000070 5245                   addq.w  #1,d5             update i + 2n, too
1 000072 BC40                   cmp.w   d0,d6
1 000074 6DEC                   blt.s   unh5              if i < n
1 000076 7A00           unh5.5  moveq   #L0,d5            filler := L0
1 000078 3C00           unh6    move.w  d0,d6             i := n
1 00007A 13856000       unh7    move.b  d5,0(a1,d6.w)     Screen[x+i, y] := filler
1 00007E 5246                   addq.w  #1,d6             i := i + 1
1 000080 BC41                   cmp.w   d1,d6
1 000082 6DF6                   blt.s   unh7              if i < 2n
1 000084 5289           unh8    addq.l  #1,a1             x := x + 1
1 000086 51CBFF9E               dbra    d3,unh2           do next x
1 00008A 51CCFF8A               dbra    d4,unh1           do next y
```

```
! 00008E 4CDF02FF            movem.l (sp)+,a1/d0-d7
! 000092 4E75                rts


                             end


0 errors detected.

program FixCurvatureOffsetGen;  { for assembly source }

const Vertical = false;

var I, Column: integer;
    Inp, Result: text;
    Offsets: array [0..511] of integer;
    Xold, Yold, X, Y, Min, Max: integer;
    Going: boolean;
    TrayName, FileName: string [20];

const Tab = ^I;

      procedure XYMove(XZ, YZ, XN, YN: integer);

      { ACM Algorithm 162: X/Y move plotting }

      var A, B, D, E, F, T, I, Move: integer;
          Xp, Yp: integer;

         function Code(J: integer): integer;
         begin
          if J = 15 then Code := 1
          else Code := J - ((J div 4) * 2);
         end;

         procedure Plot(Move: integer);
         var Dir, Pixel, I: integer;
         const OffsetX: array [0..7] of integer = ( 1, 1, 0,-1,-1,-1, 0, 1);
               OffsetY: array [0..7] of integer = ( 0, 1, 1, 1, 0,-1,-1,-1);
         begin
          if Move <= 3 then Dir := 3 - Move
          else Dir := 11 - Move;
          Xp := Xp + OffsetX[Dir];
          Yp := Yp + OffsetY[Dir];
          if Vertical then begin
             Offsets[Yp] := Xp;
             if Xp < Min then Min := Xp;
            end
          else begin
             Offsets[Xp] := Yp;
             if Yp > Max then Max := Yp;
            end;
         end;

      begin  { XYMove }
       Xp := XZ;
       Yp := YZ;
```

```
    if (XZ <> XN) or (YZ <> YN) then begin
      A := XN - XZ;
      B := YN - YZ;
      D := A + B;
      T := B - A;
      I := 0;
      if B >= 0 then I := 1;
      if D >= 0 then I := I + 2;
      if T >= 0 then I := I + 2;
      if A >= 0 then I := 8 - I else I := I + 10;
      A := abs(A);
      B := abs(B);
      F := A + B;
      D := B - A;
      if D >= 0 then begin T := A; D := -D; end  else T := B;
      E := 0;
      Move := Code(I-1);
      I := Code(I);
     repeat
       A := D + E;
       B := T + E + A;
       if B >= 0 then begin E :=    F := F - 2; Plot(I); end
       else begin E := E + T; F := F - 1; Plot(Move); end;
     until F <= 0;
    end;
  end;

begin
 for I:=0 to 511 do Offsets[I] := 0;
 Going := false;
 Write('Tray name:  ');
 readln(TrayName);
 FileName := TrayName + '.cur';
 assign(Inp,FileName);
 reset(Inp);
 while not eof(Inp) do begin
   readln(Inp,X,Y);
   if Going then XYMove(Xold,Yold,X,Y)
   else begin
     if Vertical then begin
       Offsets[Y] := X;
       Min := X;
      end
     else begin
       Offsets[X] := Y;
       Max := Y;
      end;
    end;
   Xold := X;
   Yold := Y;
   Going := true;
  end;
for I:=0 to 511 do begin
  if Offsets[I] > 0 then begin
    if Vertical then
      Offsets[I] := Offsets[I] - Min
    else
```

```
        Offsets[I] := Max - Offsets[I];
      end;
    end;
  FileName := TrayName + '.inc';
  assign(Result,FileName);
  rewrite(Result);
  writeln(Result,TrayName);
  Column := 0;
  for I:=0 to 511 do begin
    if Column = 0 then write(Result,Tab,'dc.w',Tab);
    write(Result,Offsets[I]);
    Column := Column + 1;
    if (I = 511) or (Column >= 10) then begin
      writeln(Result);
      Column := 0;
    end
    else
      write(Result,',');
  end;
  writeln(Result);
  close(Result);
end
```

FixCurvature - correct curvature in image.

```
Address Object    Statement.

                        xdef    FixCurvature

    00000001            section 1



                        include global.def          global symbol definitions
                  **    Global.def - global symbol definitions.
                  *
                  *     Copyright (C) 1986, CFA Technologies, Inc.

                  ****  Intensity level definitions.

    00000000      L0    equ     0
    00000010      L1    equ     16
    00000020      L2    equ     32
    00000030      L3    equ     48
    00000040      L4    equ     64
    00000050      L5    equ     80
    00000060      L6    equ     96
    00000070      L7    equ     112
    00000080      L8    equ     128
    00000090      L9    equ     144
    000000A0      L10   equ     160
    000000B0      L11   equ     176
    000000C0      L12   equ     192
    000000D0      L13   equ     208
```

```
Address Object     Statement.

      000000E0     L14     equ     224
      000000FF     L15     equ     255

                   ****    Useful constants.

      00000009     Yshift  equ     9                ; log 2 of X and Y coordinate bounds
      000001FF     Border  equ     (1<<(Yshift)-1   ; X and Y coordinate border

                   ****    Character constants.

      00000020     Space   equ     $20
      00000007     Bel     equ     'G'-$40
      00000008     BS      equ     'H'-$40
      00000009     Tab     equ     'I'-$40
      0000000A     LF      equ     'J'-$40
      0000000C     FF      equ     'L'-$40
      0000000D     CR      equ     'M'-$40
      0000000E     SO      equ     'N'-$40
      0000000F     SI      equ     'O'-$40
      00000011     Xon     equ     'Q'-$40
      00000013     Xoff    equ     'S'-$40
      0000001B     Esc     equ     '['-$40
      0000007F     Del     equ     $7f
      00000019     CtrlY   equ     'Y'-$40

                   ****    Constants used to control LEDs

                   * Legal codes for ButtonLight (SwitchOff also good for FingerLight)

      00000000     SwitchOff       equ     0
      00000001     YesAndNo        equ     1
      00000002     Capture         equ     2
      00000003     SwitchTest      equ     3

                   * Codes to control fluorescent lights

      00000001     FluorRoll       equ     1
      00000002     FluorSlap       equ     2

                   ****    Assembly constants

      000000FF     Background      equ     L15          background fill value

                   ***     FixCurvature - correct curvature in image.
                   *       Based on Pascal implementation by M. S. Ransom.
                   *       Converted to 68000 assembler by D. E. Germann.
                   *
                   *       Copyright (C) 1986, CFA Technologies, Inc.
                   *
                   *       entry   (a5.l) = screen image address.
```

```
Address Object       Statement.
                     *           (d0.w) = tray number.
                     *
                     *     exit  image corrected.
                     *
                     *     uses  a - none.
                     *           d - none.
                     *
                     *     calls none.

                     FixCurvature
1 000000 B07C0005          cmp.w   #4+1,d0
1 000004 6700005C          beq     fix30                   if slap prints, skip decurve
1 000008 48E7E7A0          movem.l a0/a2/d0-d2/d5-d7,-(sp) save registers
1 00000C 45FA0056          lea     Offsets(pc),a2          offset pointer table address
1 000010 E540              asl.w   #2,d0                   convert tray number to table offset
1 000012 247200FC          move.l  -4(a2,d0.w),a2          get table address for this tray

                     *     if desired, this is the place for a test for horiz/vert decurve.
                     *     Horizontal decurve.

1 000016 D5FC00000400 fix10 add.l  #(Border+1)*2,a2        move past end of table
1 00001C 2E3C00000200      move.l  #1<<Yshift,d7           y-increment
1 000022 7C09              moveq   #Yshift,d6
1 000024 7AFF              moveq   #Background,d5          fill value for end of lines
1 000026 303C01FF          move.w  #Border,d0              x := Border downto 0
1 00002A 7400        fix11 moveq   #0,d2
1 00002C 3422              move.w  -(a2),d2                off := Offsets[x]
1 00002E 6F2A              ble.s   fix14                   if not correcting this column
1 000030 323C01FF          move.w  #Border,d1
1 000034 9242              sub.w   d2,d1                   y := Border downto off
1 000036 207C0003FE00      move.l  #Border<<Yshift,a0
1 00003C D1CD              add.l   a5,a0                   Screen[0, Border]
1 00003E D0C0              add.w   d0,a0                   Screen[x, Border]
1 000040 EDA2              asl.l   d6,d2                   convert offset to y-coordinate address
1 000042 4482              neg.l   d2                      generate -offset value
1 000044 10B02800    fix12 move.b  0(a0,d2.l),(a0)         Screen[x, y] := Screen[x, y-off]
1 000048 91C7              sub.l   d7,a0                   y := y - 1
1 00004A 51C9FFF8          dbra    d1,fix12                if more pixels to move in this column
1 00004E 3412              move.w  (a2),d2                 off := Offsets[x]
1 000050 5342              subq.w  #1,d2                   i := off-1 downto 0
1 000052 1085        fix13 move.b  d5,(a0)                 clear pixel
1 000054 91C7              sub.l   d7,a0                   y := y - 1
1 000056 51CAFFFA          dbra    d2,fix13                if more pixels to clear in this column
1 00005A 51C8FFCE    fix14 dbra    d0,fix11                if more columns to decurve
1 00005E 4CDF05E7    fix20 movem.l (sp)+,a0/a2/d0-d2/d5-d7 restore registers
1 000062 4E75        fix30 rts

1 000064 000000740000 Offsets dc.l Curve1,Curve2,Curve3,Curve4
         047400000874
         00000C74

                           nolist

                           end

0 errors detected.
```

```
program ChangeXConstantGen;  { for assembler source }
const Tab = ^I;
      Border = 511;
var I, Column, tray, MeetPoint: integer;
    Numerator, Denominator, LeftEdge, RightEdge: integer;
    Result: text;
    X, OldX, OldMiddle, NewMiddle: integer;
    Offsets: array [0..511] of integer;
    Answer: char;
    Linear, AlignEdge, Shrinking: boolean;

   procedure GenerateOffsets;
   var I, OldX, Y, NewX, PreviousOldX, Xincrement, Alignment: integer;
       Going: boolean;
       CoordFile: text;
       FileName: string [80];

         procedure XYMove(XZ, YZ, XN, YN: integer);

        { ACM Algorithm 162: X/Y move plotting }

         var A, B, D, E, F, T, I, Move: integer;
             Xp, Yp: integer;

            function Code(J: integer): integer;
            begin
             if J = 15 then Code := 1
             else Code := J - ((J div 4) * 2);
            end;

            procedure Plot(Move: integer);
            var Dir, Pixel, I: integer;
            const OffsetX: array [0..7] of integer = ( 1, 1, 0,-1,-1,-1, 0, 1);
                  OffsetY: array [0..7] of integer = ( 0, 1, 1, 1, 0,-1,-1,-1);
            begin
             if Move <= 3 then Dir := 3 - Move
             else Dir := 11 - Move;
             Xp := Xp + OffsetX[Dir];
             Yp := Yp + OffsetY[Dir];
             if (Yp >= 0) and (Yp <= Border) then
                Offsets[Yp] := Xp;
            end;

        begin  { XYMove }
         Xp := XZ;
         Yp := YZ;
         if (XZ <> XN) or (YZ <> YN) then begin
            A := XN - XZ;
            B := YN - YZ;
            D := A + B;
            T := B - A;
            I := 0;
            if B >= 0 then I := 2;
            if D >= 0 then I := I + 2;
            if T >= 0 then I := I + 2;
            if A >= 0 then I := 8 - I else I := I + 16;
            A := abs(A);
```

```
        B := abs(B);
        F := A + B;
        D := B - A;
        if D >= 0 then begin T := A; D := -D; end  else T := B;
        E := 0;
        Move := Code(I-1);
        I := Code(I);
        repeat
          A := D + E;
          B := T + E + A;
          if B >= 0 then begin E := A; F := F - 2; Plot(I); end
          else begin E := E + T; F := F - 1; Plot(Move); end;
        until F <= 0;
       end;
     end;

begin  { GenerateOffsets }
 write('Enter X increment, in dots:            ');
 readln(Xincrement);
 write('Enter coordinate file name:            ');
 readln(FileName);
 assign(CoordFile,FileName);
 reset(CoordFile);
 for I:=0 to 511 do Offsets[I] := -1;
 Going := false;
 NewX := 0;
 while not eof(CoordFile) do begin
    readln(CoordFile,OldX,Y);
    if Going then begin
       XYMove(PreviousOldX,NewX,OldX,NewX+Xincrement);
       NewX := NewX + Xincrement;
      end
    else begin
       Offsets[NewX] := OldX;
       LeftEdge := OldX;
      end;
    PreviousOldX := OldX;
    Going := true;
   end;
 close(CoordFile);
 if NewX > Border then NewX := Border;
 Shrinking := (NewX < (Offsets[NewX] - LeftEdge));
 if not AlignEdge then begin
    I := 0;
    while (I < NewX) and (Offsets[I] < OldMiddle) do I := I + 1;
    if ((I = 0) and (Offsets[I] > OldMiddle)) or
       (Offsets[I] < OldMiddle) then
      begin
       writeln('Old middle is outside picture bounds.');
       Alignment := 0;
      end
    else Alignment := NewMiddle - I;
    if Alignment >= 0 then begin
       for I:=NewX downto 0 do begin
          Offsets[I+Alignment] := Offsets[I];
         end;
```

```
      for I:=Alignment-1 downto 0 do
         Offsets[I] := -1;
      end
    else begin
      for I:=-Alignment to NewX do begin
         Offsets[I+Alignment] := Offsets[I];
        end;
      for I:=NewX+Alignment+1 to NewX do
         Offsets[I] := -1;
      end;
    end;
  end;  { GenerateOffsets }


begin
 assign(Result,'changex.def');
 rewrite(Result);
 writeln(Result);
 writeln(Result,'Shrinking',Tab,'equ',Tab,'-4',Tab,
   'offset of shrink or expand flag');
writeln(Result,'MeetPoint',Tab,'equ',Tab,'-2',Tab,'offset of MeetPoint');
close(Result);
assign(Result,'changex.inc');
rewrite(Result);
for tray := 1 to 5 do begin
   writeln('Tray ', tray:1, ': ');
   write('Linear or Non-linear change?          ');
   readln(Answer);
   Linear := ((Answer = 'L') or (Answer = 'l'));
   write('Align on left edge or middle?         ');
   readln(Answer);
   AlignEdge := ((Answer = 'l') or (Answer = 'L'));
   if not AlignEdge then begin
      write('Enter old middle X coordinate:         ');
      readln(OldMiddle);
      write('Enter new middle X coordinate:         ');
      readln(NewMiddle);
     end;
   if not Linear then GenerateOffsets
   else begin
      write('Enter ratio numerator and denominator:  ');
      readln(Numerator,Denominator);
      Shrinking := (Numerator < Denominator);
      write('Enter Left and Right edge coordinates:  ');
      readln(LeftEdge,RightEdge);
      if AlignEdge then begin
         for X:=0 to Border do begin
            OldX := round(((X+0.0) * Denominator / Numerator) + LeftEdge);
            if OldX < LeftEdge then OldX := -1;
            if OldX > RightEdge then OldX := -1;
            Offsets[X] := OldX;
           end;
        end
      else begin
         for X:=0 to Border do begin
            OldX := round(((((X-NewMiddle)+0.0) * Denominator) / Numerator)
```

```
                + OldMiddle);
            if OldX < LeftEdge then OldX := -1;
            if OldX > RightEdge then OldX := -1;
            Offsets[X] := OldX;
           end;
        end;
     end;
   X := 0;
   while (X < Border) and (X <> Offsets[X]) do begin
      if Offsets[X] >= 0 then begin
         if (Shrinking and (X > Offsets[X])) or
            ((not Shrinking) and (X < Offsets[X])) then
            MeetPoint := Border
         else
            MeetPoint := -1;
           end;
      X := X + 1;
     end;
   if X = Offsets[X] then MeetPoint := X;

   writeln(Result);
   writeln(Result,'$',Tab,'Tray ',tray:1);
   writeln(Result);
   if Shrinking then
      writeln(Result,Tab,'dc.w',Tab,'$ff',Tab,'shrinking')
   else
      writeln(Result,Tab,'dc.w',Tab,'0',Tab,'not shrinking');
   writeln(Result,Tab,'dc.w',Tab,MeetPoint);
   writeln(Result,'Off',tray:1);
        Column := 0;
        for I:=0 to Border do begin
           if Column = 0 then write(Result,'dc.w',Tab);
           write(Result,Offsets[I]);
           Column := Column + 1;
           if (I = Border) or (Column >= 10) then begin
              writeln(Result);
              Column := 0;
             end
           else
              write(Result,',');
          end;
        writeln(Result);
      end;
    writeln(Result);
    writeln(Result,'Offsets');
    for tray := 1 to 5 do
       writeln(Result,Tab,'dc.l',Tab,'Off',tray:1);
    close(Result);
   end.
```

ChangeX - change ... ge in X direction.

```
Address Object          Statement.

                                xdef    ChangeX

        00000001                section 1

                                include global.def              global symbol definitions
                        **      Global.def - global symbol definitions.
                        *
                        *       Copyright (C) 1986, CFA Technologies, Inc.

                        ****    Intensity level definitions.

        00000000        L0      equ     0
        00000010        L1      equ     16
        00000020        L2      equ     32
        00000030        L3      equ     48
        00000040        L4      equ     64
        00000050        L5      equ     80
        00000060        L6      equ     96
        00000070        L7      equ     112
        00000080        L8      equ     128
        00000090        L9      equ     144
        000000A0        L10     equ     160
        000000B0        L11     equ     176
        000000C0        L12     equ     192
        000000D0        L13     equ     208
        000000E0        L14     equ     224
        000000FF        L15     equ     255

                        ****    Useful constants.

        00000009        Yshift  equ     9               ; log 2 of X and Y coordinate bounds
        000001FF        Border  equ     (1<<(Yshift)-1  ; X and Y coordinate border

                        ****    Character constants.

        00000020        Space   equ     $20
        00000007        Bel     equ     'G'-$40
        00000008        BS      equ     'H'-$40
        00000009        Tab     equ     'I'-$40
        0000000A        LF      equ     'J'-$40
        0000000C        FF      equ     'L'-$40
        0000000D        CR      equ     'M'-$40
        0000000E        SO      equ     'N'-$40
        0000000F        SI      equ     'O'-$40
        00000011        Xon     equ     'Q'-$40
        00000013        Xoff    equ     'S'-$40
        0000001B        Esc     equ     '['-$40
```

```
Address Object          Statement.
        0000007F        Del     equ     $7f
        00000019        CtrlY   equ     'Y'-$40

                        ****    Constants used to control LEDs

                        * Legal codes for ButtonLight (SwitchOff also good for FingerLight)

        00000000        SwitchOff       equ     0
        00000001        YesAndNo        equ     1
        00000002        Capture         equ     2
        00000003        SwitchTest      equ     3

                        * Codes to control fluorescent lights

        00000001        FluorRoll       equ     1
        00000002        FluorSlap       equ     2

                                include changex.def             changex symbol definitions

        FFFFFFFC        Shrinking       equ     -4      offset of shrink or expand flag
        FFFFFFFE        MeetPoint       equ     -2      offset of MeetPoint

                        ****    Assembly constants.

        000000FF        Background      equ     L15             background fill value

                        ***     ChangeX - change image in X direction.
                        *       Based on Pascal implementation by M. S. Ransom.
                        *       Converted to 68000 assembler by D. E. Germann.
                        *
                        *       Copyright (C) 1986, CFA Technologies, Inc.
                        *
                        *       entry   (a0.l) = screen image address.
                        *               (d0.w) = tray number.
                        *
                        *       exit    image corrected.
                        *
                        *       uses    a - none.
                        *               d - none.
                        *
                        *       calls   move.

1 000000 48E7FE38       ChangeX movem.l a2-a4/d0-d6,-(sp)       save registers
1 000004 45FA14A4               lea     Offsets(pc),a2          offset pointer table address
1 000008 E540                   asl.w   #2,d0                   convert tray number to table offset
1 00000A 247200FC               move.l  -4(a2,d0.w),a2          get table address for this tray
1 00000E 4A6AFFFC               tst.w   Shrinking(a2)
```

```
Address Object         Statement.
1 000012 6722                   beq.s   chx2                   if expanding image
1 000014 302AFFFE               move.w  MeetPoint(a2),d0       initial x := MeetPoint
1 000018 7200                   moveq   #0,d1                  final x := 0
1 00001A 74FF                   moveq   #-1,d2                 count down
1 00001C B041                   cmp.w   d1,d0
1 00001E 6D02                   blt.s   chx1                   if nothing to do on this side
1 000020 613A                   bsr.s   move                   compress left half of image
1 000022 302AFFFE      chx1     move.w  MeetPoint(a2),d0
1 000026 5240                   addq.w  #1,d0                  initial x := MeetPoint+1
1 000028 323C01FF               move.w  #Border,d1             final x := Border
1 00002C 7401                   moveq   #1,d2                  count up
1 00002E B041                   cmp.w   d1,d0
1 000030 6E24                   bgt.s   chx4                   if nothing to do on this side
1 000032 6128                   bsr.s   move                   compress right half of image
1 000034 6020                   bra.s   chx4

1 000036 7000          chx2     moveq   #0,d0                  initial x := 0
1 000038 322AFFFE               move.w  MeetPoint(a2),d1       final x := MeetPoint
1 00003C 7401                   moveq   #1,d2                  count up
1 00003E B041                   cmp.w   d1,d0
1 000040 6E02                   bgt.s   chx3                   if nothing to do on this side
1 000042 6118                   bsr.s   move                   expand left half of image
1 000044 303C01FF      chx3     move.w  #Border,d0             initial x := Border
1 000048 322AFFFE               move.w  MeetPoint(a2),d1
1 00004C 5241                   addq.w  #1,d1                  final x := MeetPoint+1
1 00004E 74FF                   moveq   #-1,d2                 count down
1 000050 B041                   cmp.w   d1,d0
1 000052 6D02                   blt.s   chx4                   if nothing to do on this side
1 000054 6106                   bsr.s   move                   expand right half of image
1 000056 4CDF1C7F      chx4     movem.l (sp)+,a2-a4/d0-d6      restore registers
1 00005A 4E75                   rts


                       **       move - expand or compress portion of image.
                       *
                       *        entry   (a0.l) = screen address.
                       *                (a2.l) = offset table base address.
                       *                (d0.w) = inital x.
                       *                (d1.w) = final x.
                       *                (d2.w) = x increment (+/- 1).
                       *
                       *        exit    screen portion expanded or compressed
                       *
                       *        uses    a - 3, 4.
                       *                d - 0, 1, 3, 5, 6.
                       *
                       *        calls   none.

1 00005C D242          move     add.w   d2,d1                  final value + increment
1 00005E 287C00000200           move.l  #1<<Yshift,a4          y increment
1 000064 7AFF                   moveq   #Background,d5         preload background value
1 000066 3C3C01FF      mov1     move.w  #Border,d6             y := 0 to Border (d6 counts down)
1 00006A 2648                   move.l  a0,a3                  Screen[0, y]
```

```
Address Object         Statement.
1 00006C 3600                  move.w  d0,d3
1 00006E D643                  add.w   d3,d3
1 000070 36323000              move.w  0(a2,d3.w),d3         OldX := Offset[x]
1 000074 6B14                  bmi.s   mov4                  if this column is to be cleared
1 000076 17B330000000   mov2   move.b  0(a3,d3.w),0(a3,d0.w) Screen[x, y] := Screen[OldX, y]
1 00007C D7CC                  add.l   a4,a3                 y := y + 1
1 00007E 51CEFFF6              dbra    d6,mov2               if more pixels to move in this column
1 000082 D042           mov3   add.w   d2,d0                 x := x + increment
1 000084 B041                  cmp.w   d1,d0
1 000086 66DE                  bne.s   mov1                  if more columns to process
1 000088 4E75                  rts

1 00008A 17850000       mov4   move.b  d5,0(a3,d0.w)         Screen[x, y] := Background
1 00008E D7CC                  add.l   a4,a3                 y := y + 1
1 000090 51CEFFF8              dbra    d6,mov4               if more pixels to clear in this column
1 000094 60EC                  bra.s   mov3



                               nolist



                               end


0 errors detected.

program ChangeYConstantGen;  { for assembler source }
const Tab = ^I;
      Border = 511;
var I, Column, tray: integer;
    Result: text;
    Y, OldY, MeetPoint: integer;
    ExpansionFactor: real;
    Numerator, Denominator, OldMiddle, NewMiddle, TopEdge, BottomEdge: integer;
    Offsets: array [0..511] of integer;
    Answer: char;
begin
 write('Expansion coefficient: ');
 readln(ExpansionFactor);
 assign(Result,'changey.def');
 rewrite(Result);
 writeln(Result,'Numerator',Tab,'equ',Tab,'-6',Tab,'offset of Numerator');
 writeln(Result,'Denominator',Tab,'equ',Tab,'-4',Tab,'offset of Denominator');
 writeln(Result,'MeetPoint',Tab,'equ',Tab,'-2',Tab,'offset of MeetPoint');
 close(Result);
 assign(Result,'changey.inc');
 rewrite(Result);
 for tray := 1 to 5 do begin
    write('Numerator and denominator for tray ', tray:1, ': ');
    readln(Numerator, Denominator);
    Numerator := round(Numerator * ExpansionFactor);
    write('Enter Top and Bottom edge coordinates:  ');
```

```
readln(TopEdge,BottomEdge);
write('Align on top edge or middle?            ');
readln(Answer);
if (Answer = 't') or (Answer = 'T') then begin
   for Y:=0 to Border do begin
      OldY := round(((Y+0.0) * Denominator / Numerator) + TopEdge);
      if OldY < TopEdge then OldY := -1;
      if OldY > BottomEdge then OldY := -1;
      Offsets[Y] := OldY;
     end;
   if (Numerator-Denominator) > 0 then begin
      if ((TopEdge+0.0)*Numerator) > ((Border+0.0)*(Numerator-Denominator))
         then MeetPoint := Border
      else if TopEdge < 0 then MeetPoint := -1
      else MeetPoint :=
         round((TopEdge+0.0) * Numerator / (Numerator-Denominator));
     end
   else if (Numerator-Denominator) < 0 then begin
      if ((TopEdge+0.0)*Numerator) < ((Border+0.0)*(Numerator-Denominator))
         then MeetPoint := Border
      else if TopEdge > 0 then MeetPoint := -1
      else MeetPoint :=
         round((TopEdge+0.0) * Numerator / (Numerator-Denominator));
     end
   else begin
      if TopEdge >= 0 then MeetPoint := Border
      else MeetPoint := -1;
     end;
  end
else begin
   write('Enter old middle Y coordinate:            ');
   readln(OldMiddle);
   write('Enter new middle Y coordinate:            ');
   readln(NewMiddle);
   for Y:=0 to Border do begin
      OldY := round((((Y-NewMiddle)+0.0) * Denominator) / Numerator)
            + OldMiddle);
      if OldY < TopEdge then OldY := -1;
      if OldY > BottomEdge then OldY := -1;
      Offsets[Y] := OldY;
  end;
if (Numerator-Denominator) > 0 then begin
   if ((OldMiddle+0.0)*Numerator - (NewMiddle+0.0)*Denominator) >
        ((Border+0.0)*(Numerator-Denominator))
      then MeetPoint := Border
   else if ((OldMiddle+0.0)*Numerator) < ((NewMiddle+0.0)*Denominator)
      then MeetPoint := -1
   else MeetPoint :=
      round( ((OldMiddle+0.0)*Numerator - (NewMiddle+0.0)*Denominator) /
             (Numerator - Denominator) );
  end
else if (Numerator-Denominator) < 0 then begin
   if ((OldMiddle+0.0)*Numerator - (NewMiddle+0.0)*Denominator) <
        ((Border+0.0)*(Numerator-Denominator))
      then MeetPoint := Border
   else if ((OldMiddle+0.0)*Numerator) > ((NewMiddle+0.0)*Denominator)
      then MeetPoint := -1
```

```
        else MeetPoint :=
           round( ((OldMiddle+0.0)*Numerator - (NewMiddle+0.0)*Denominator) /
                  (Numerator - Denominator) );
       end
     else begin
        if NewMiddle > OldMiddle then MeetPoint := -1
        else MeetPoint := Border;
       end;
    end;
   if MeetPoint < 0 then MeetPoint := -1;
   if MeetPoint > Border then MeetPoint := Border;
   writeln(Result);
   writeln(Result,'*',Tab,'Tray ',tray:1,': ');
   writeln(Result);
   writeln(Result,Tab,'dc.w',Tab,Numerator,',',Denominator);
   writeln(Result,Tab,'dc.w',Tab,MeetPoint);
   writeln(Result,'Off',tray:1);
   Column := 0;
   for I:=0 to Border do begin
      if Column = 0 then write(Result,Tab,'dc.w',Tab);
      write(Result,Offsets[I]);
      Column := Column + 1;
      if (I = Border) or (Column >= 10) then begin
         writeln(Result);
         Column := 0;
        end
      else
         write(Result,',');
     end;
   writeln(Result);
  end;
 writeln(Result);
 writeln(Result,'Offsets');
 for tray := 1 to 5 do
    writeln(Result,Tab,'dc.l',Tab,'Off',tray:1);
 close(Result);
end.
```

```
                 ChangeY - change  ge in Y direction

Address Object        Statement.

                            xdef     ChangeY


      00000001              section 1


                            include global.def            global symbol definitions
                      **    Global.def - global symbol definitions.
                      *
                      *     Copyright (C) 1986, CFA Technologies, Inc.


                      ****  Intensity level definitions.

      00000000        L0    equ      0
```

```
00000010        L1      equ     16
00000020        L2      equ     32
00000030        L3      equ     48
00000040        L4      equ     64
00000050        L5      equ     80
00000060        L6      equ     96
00000070        L7      equ     112
00000080        L8      equ     128
00000090        L9      equ     144
000000A0        L10     equ     160
000000B0        L11     equ     176
000000C0        L12     equ     192
000000D0        L13     equ     208
000000E0        L14     equ     224
000000FF        L15     equ     255

                ****    Useful constants.

00000009        Yshift  equ     9                 ; log 2 of X and Y coordinate bounds
000001FF        Border  equ     (1<<Yshift)-1     ; X and Y coordinate border

                ****    Character constants.

00000020        Space   equ     $20
00000007        Bel     equ     'G'-$40
00000008        BS      equ     'H'-$40
00000009        Tab     equ     'I'-$40
0000000A        LF      equ     'J'-$40
0000000C        FF      equ     'L'-$40
0000000D        CR      equ     'M'-$40
0000000E        SO      equ     'N'-$40
0000000F        SI      equ     'O'-$40
00000011        Xon     equ     'Q'-$40
00000013        Xoff    equ     'S'-$40
0000001B        Esc     equ     '['-$40
0000007F        Del     equ     $7f
00000019        CtrlY   equ     'Y'-$40

                ****    Constants used to control LEDs

                * Legal codes for ButtonLight (SwitchOff also good for FingerLight)

00000000        SwitchOff       equ     0
00000001        YesAndNo        equ     1
00000002        Capture         equ     2
00000003        SwitchTest      equ     3

                * Codes to control fluorescent lights

00000001        FluorRoll       equ     1
00000002        FluorSlap       equ     2

                        include changey def             changey symbol definitions
FFFFFFFA        Numerator       equ     -6      offset of Numerator
FFFFFFFC        Denominator     equ     -4      offset of Denominator
FFFFFFFE        MeetPoint       equ     -2      offset of MeetPoint
```

```
                     ****   Assembly constants.

FFFFFFFF             Background      equu    $FFFFFFFF       background fill value


                     ***    ChangeY - change image in Y direction.
                     *      Based on Pascal implementation by M. S. Ransom.
                     *      Converted to 68000 assembler by D. E. Germann.
                     *
                     *      Copyright (C) 1986, CFA Technologies, Inc.
                     *
                     *      entry   (a0.l) = screen image address.
                     *              (d0.w) = tray number.
                     *
                     *      exit    image corrected.
                     *
                     *      uses    a - none.
                     *              d - none.
                     *
                     *      calls   move.
Address Object       Statement.
1 000000 48E7FE38    ChangeY movem.l a2-a4/d0-d6,-(sp)       save registers
1 000004 45FA14B4            lea     Offsets(pc),a2          offset pointer table address
1 000008 E540                asl.w   #2,d0                   convert tray number to table offset
1 00000A 247200FC            move.l  -4(a2,d0.w),a2          get table address for this tray
1 00000E 3C2AFFFA            move.w  Numerator(a2),d6
1 000012 BC6AFFFC            cmp.w   Denominator(a2),d6
1 000016 6C22                bge.s   chy2                    if expanding image
1 000018 302AFFFE            move.w  MeetPoint(a2),d0        initial y := MeetPoint
1 00001C 7200                moveq   #0,d1                   final y := 0
1 00001E 74FF                moveq   #-1,d2                  count down
1 000020 B041                cmp.w   d1,d0
1 000022 6D02                blt.s   chy1                    if nothing to do on this side
1 000024 613A                bsr.s   move                    compress top half of image
1 000026 302AFFFE    chy1    move.w  MeetPoint(a2),d0
1 00002A 5240                addq.w  #1,d0                   initial y := MeetPoint+1
1 00002C 323C01FF            move.w  #Border,d1              final y := Border
1 000030 7401                moveq   #1,d2                   count up
1 000032 B041                cmp.w   d1,d0
1 000034 6E24                bgt.s   chy4                    if nothing to do on this side
1 000036 6128                bsr.s   move                    compress bottom half of image
1 000038 6020                bra.s   chy4

1 00003A 7000        chy2    moveq   #0,d0                   initial y := 0
1 00003C 322AFFFE            move.w  MeetPoint(a2),d1        final y := MeetPoint
1 000040 7401                moveq   #1,d2                   count up
1 000042 B041                cmp.w   d1,d0
1 000044 6E02                bgt.s   chy3                    if nothing to do on this side
1 000046 6118                bsr.s   move                    expand top half of image
1 000048 303C01FF    chy3    move.w  #Border,d0              initial y := Border
1 00004C 322AFFFE            move.w  MeetPoint(a2),d1
1 000050 5241                addq.w  #1,d1                   final y := MeetPoint+1
1 000052 74FF                moveq   #-1,d2                  count down
1 000054 B041                cmp.w   d1,d0
```

```
Address Object          Statement.
1 000056 6D02                    blt.s   chy4                       if nothing to do on this side
1 000058 6106                    bsr.s   move                       expand bottom half of image
1 00005A 4CDF1C7F       chy4     movem.l (sp)+,a2-a4/d0-d6          restore registers
1 00005E 4E75                    rts


                        **       move - expand or compress portion of image.
                        *
                        *        entry   (a0.l) = screen address.
                        *                (a2.l) = offset table base address.
                        *                (d0.w) = inital y.
                        *                (d1.w) = final y
                        *                (d2.w) = y increment (+/- 1).
                        *
                        *        exit    screen portion expanded or compressed.
                        *
                        *        uses    a - 3, 4
                        *                d - 0, 1, 3, 4, 5, 6.
                        *
                        *        calls   none.

1 000060 D242           move     add.w   d2,d1                      final value + increment
1 000062 7AFF                    moveq   #Background,d5             preload background value
1 000064 7809                    moveq   #Yshift,d4
1 000066 3C3C0080       mov1     move.w  #(Border+1)/4,d6           x := 0 to Border (d6 counts down)
1 00006A 7600                    moveq   #0,d3
1 00006C 3600                    move.w  d0,d3
1 00006E E9A3                    asl.l   d4,d3                      convert to coordinate offset
1 000070 2648                    move.l  a0,a3
1 000072 D7C3                    add.l   d3,a3                      Screen[0, y]
1 000074 7600                    moveq   #0,d3
1 000076 3600                    move.w  d0,d3
1 000078 D643                    add.w   d3,d3
1 00007A 36323000                move.w  0(a2,d3.w),d3              OldY := Offset[y]
1 00007E 6B14                    bmi.s   mov4                       if this row is to be cleared
1 000080 E9A3                    asl.l   d4,d3                      convert to coordinate offset
1 000082 2848                    move.l  a0,a4
1 000084 D9C3                    add.l   d3,a4                      Screen[0, OldY]
1 000086 26DC           mov2     move.l  (a4)+,(a3)+                Screen[x, y] := Screen[x, OldY]
1 000088 51CEFFFC                dbra    d6,mov2                    if more pixels to move in this row
1 00008C D042           mov3     add.w   d2,d0                      y := y + increment
1 00008E B041                    cmp.w   d1,d0
1 000090 66D4                    bne.s   mov1                       if more rows to process
1 000092 4E75                    rts

1 000094 26C5           mov4     move.l  d5,(a3)+                   Screen[x, y] := Background
1 000096 51CEFFFC                dbra    d6,mov4                    if more pixels to clear in this row
1 00009A 60F0                    bra.s   mov3

                                 nolist

                                 end

0 errors detected.
```

Bitmap - conver(...)y-scale image to b&w bitma(...)

```
Address Object        Statement.

                              xdef    Bitmap

      00000001                section 1



                              include global.def            include global symbol definitions
                      **      Global.def - global symbol definitions.
                      *
                      *       Copyright (C) 1986, CFA Technologies, Inc.


                      ****    Intensity level definitions.

      00000000        L0      equ     0
      00000010        L1      equ     16
      00000020        L2      equ     32
      00000030        L3      equ     48
      00000040        L4      equ     64
      00000050        L5      equ     80
      00000060        L6      equ     96
      00000070        L7      equ     112
      00000080        L8      equ     128
      00000090        L9      equ     144
      000000A0        L10     equ     160
      000000B0        L11     equ     176
      000000C0        L12     equ     192
      000000D0        L13     equ     208
      000000E0        L14     equ     224
      000000FF        L15     equ     255

                      ****    Useful constants.

      00000009        Yshift  equ     9               ; log 2 of X and Y coordinate bounds
      000001FF        Border  equ     (1<<Yshift)-1   ; X and Y coordinate border

                      ****    Character constants.

      00000020        Space   equ     $20
      00000007        Bel     equ     'G'-$40
      00000008        BS      equ     'H'-$40
      00000009        Tab     equ     'I'-$40
      0000000A        LF      equ     'J'-$40
      0000000C        FF      equ     'L'-$40
      0000000D        CR      equ     'M'-$40
      0000000E        SO      equ     'N'-$40
      0000000F        SI      equ     'O'-$40
      00000011        Xon     equ     'Q'-$40
      00000013        Xoff    equ     'S'-$40
      0000001B        Esc     equ     '['-$40
      0000007F        Del     equ     $7f
```

```
Address Object          Statement.
        00000019        CtrlY   equ     'Y'-$40

                        ****    Constants used to control LEDs

                        * Legal codes for ButtonLight (SwitchOff also good for FingerLight)

        00000000        SwitchOff       equ     0
        00000001        YesAndNo        equ     1
        00000002        Capture         equ     2
        00000003        SwitchTest      equ     3

                        * Codes to control fluorescent lights

        00000001        FluorRoll       equ     1
        00000002        FluorSlap       equ     2



        00000040        BitBytes        equ     (Border+1)/8    number of bytes/line in bitmap image



                        ***     Bitmap - convert grey-scale image to b&w bitmap.
                        *       Implemented in 68000 assembler by D. E. Germann.
                        *
                        *       Copyright (C) 1986, CFA Technologies, Inc.
                        *
                        *       entry   (a1.l) = input screen image address, 512 x 512 x 8.
                        *               (a2.l) = output bitmap address, 512 x 512 x 1, packed.
                        *               (d0.b) = black/white threshold.
                        *
                        *       exit    image packed.
                        *
                        *       uses    a - none
                        *               d - none
                        *
                        *       calls   none.

1 000000 48E7F760       Bitmap  movem.l a1-a2/d0-d3/d5-d7,-(sp) save registers
1 000004 1600                   move.b  d0,d3
1 000006 7CFF                   moveq   #-1,d6                  initialize bit accumulator
1 000008 3E3C8000               move.w  #1<<(16-1),d7           bit counter
1 00000C 7AFF                   moveq   #-1,d5                  initialize bit mask
1 00000E 343C01FF               move.w  #Border,d2
1 000012 3002                   move.w  d2,d0                   y := 0 to Border
1 000014 3202           bit1    move.w  d2,d1                   x := 0 to Border
1 000016 E35E           bit2    rol.w   #1,d6                   position accumulator for next bit
1 000018 B619                   cmp.b   (a1)+,d3
1 00001A 53C5                   sls     d5
1 00001C 5305                   subq.b  #1,d5                   d5.w is FFFE if >= LS  FFFF if
1 00001E CC45                   and.w   d5,d6                   clear output pixel if necessary
```

```
Address Object      Statement.
! 000020 E35F                rol.w   #1,d7                     advance output bit counter
! 000022 6B0E                bmi.s   bit4                      if complete word
! 000024 51C9FFF0   bit3     dbra    d1,bit2                   if more bytes in this line
! 000028 51C8FFEA            dbra    d0,bit1                   if more lines to convert
! 00002C 4CDF06EF            movem.l (sp)+,a1-a2/d0-d3/d5-d7  restore registers
! 000030 4E75                rts

! 000032 34C6       bit4     move.w  d6,(a2)+                  store word
! 000034 7CFF                moveq   #-1,d6                    reinitialize bit accumulator
! 000036 51C9FFDE            dbra    d1,bit2                   if more bytes in this line
! 00003A 51C8FFD8            dbra    d0,bit1                   if more lines to convert
! 00003E 4CDF06EF            movem.l (sp)+,a1-a2/d0-d3/d5-d7  restore registers
! 000042 4E75                rts



                             end

0 errors detected.
```

What is claimed is:

1. A method for operating programmable computing means to illumination equalize input pixel values of an array of input pixel values characteristic of a fingerprint image so as to produce an illumination equalized array of pixel values characteristic of an illumination equalized image, including:

receiving an array of input pixel values characteristic of a fingerprint image;

selecting equalizing subarrays of input pixel values, each including an input pixel value to be illumination equalized;

generating subarray average values as a function of the pixel values within the equalizing subarrays;

subtracting the subarray average values from the corresponding pixel values being equalized to generate pixel difference values;

adding a predetermined constant to the pixel difference values to generate intermediate illumination equalized pixel values;

setting the illumination equalized pixel values equal to a predetermined minimum pixel value if the corresponding intermediate illumination equalized pixel values are less than the minimum pixel value;

setting the illumination equalized pixel values equal to the corresponding intermediate illumination equalized pixel values if the corresponding intermediate illumination equalized pixel values are greater than or equal to the minimum pixel value, and less than or equal to a predetermined maximum pixel value;

setting the illumination equalized pixel values equal to the maximum pixel value if the corresponding intermediate illumination equalized pixel values are greater than the maximum pixel value; and

storing the illumination equalized pixel values as an array of illumination equalized pixel values characteristic of the fingerprint image.

2. The method of claim 1 wherein selecting equalizing subarrays comprises selecting equalizing subarrays, each including an input pixel value to be illumination equalized and a plurality of input pixel values adjacent to and surrounding the pixel value to be illumination equalized.

3. The method of claim 2 wherein selecting equalizing subarrays comprises selecting eight-by-eight subarrays of input pixel values.

4. The method of claim 1 wherein generating subarray average values includes, for each subarray, summing the pixel values of the subarray and dividing the sum by the number of pixel values summed.

5. The method of claim 1 wherein adding a predetermined constant to the pixel difference values includes adding a constant determined as a function of noise in the fingerprint image.

6. The method of claim 1 wherein adding a predetermined constant includes adding a constant characteristic of an expected average illumination of the image.

7. The method of claim 1 wherein adding a predetermined constant includes adding a constant representative of a pixel value halfway between the maximum pixel value and the minimum pixel value.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,811,414

DATED : March 7, 1989

INVENTOR(S) : Glenn M. Fishbine et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Insert the following before line 1 of the specification:

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